

REPORTS

OF THE LATE

JOHN SMEATON, F.R.S.

MADE ON

VARIOUS OCCASIONS,

IN THE COURSE OF HIS EMPLOYMENT

AS

A CIVIL ENGINEER.

IN THREE VOLUMES,

VOL. III.

LONDON:

PRINTED FOR LONGMAN, HURST, REES, ORME, AND BROWN,
PATERNOSTER-ROW.

1812.

CONTENTS.

LYNN HARBOUR.		Page
REPORT of J. Smeaton, engineer, relative to the harbour of Lynn, in Norfolk,	-	1
WELLS HARBOUR.		
Report of J. Smeaton upon the state and condition of Wells harbour, in the county of Norfolk,	-	18
ABERDEEN HARBOUR, &c.		
Report of J. Smeaton upon the harbour of the city of Aberdeen,	-	38
Report of J. Smeaton upon the in-run of the seas into the harbour of Aberdeen, in easterly winds,	-	47
Report of J. Smeaton concerning the bridge of Dee, near the city of Aberdeen; and of the common mills of the said city,	-	51
DUNDEE HARBOUR.		
Report of J. Smeaton on the harbour of Dundee,	-	54
DUNBAR HARBOUR.		
Report of John Smeaton on the harbour of Dunbar,	-	57
PORT PATRICK HARBOUR.		
Report of J. Smeaton upon the harbour of Port Patrick, in the shire of Galloway; with a projection for rendering the same safe and commodious for vessels of eight feet draft of water,	-	69
Explanation of the plan for completing the interior of the harbour of Port Patrick,	-	68
Directions to Mr. Gwin for the execution of the interior, or flank pier, for completing the interior harbour of Port Patrick,	-	71
RAMSGATE HARBOUR.		
Historical report on Ramsgate harbour, by J. Smeaton, 1791,	-	74

CONTENTS.

Page

SANDWICH HAVEN.

Report on John Smeaton on the state of Sandwich haven, - - 129

DOVER HARBOUR.

Report of J. Smeaton upon the harbour of Dover, - - 134
 Operation of the turning-gate sluices for Dover harbour, - - 136
 Estimate for erecting one of the turning-gate sluices proposed at Dover, - - 148

AYR HARBOUR.

Report of John Smeaton upon the harbour of Ayr, - - 151

HULL QUAYS, DOCKS, &c.

Report of J. Smeaton on the projected quays at Hull, - - 155
 Appendix to the above report, - - 157
 Report of J. Smeaton and John Wooler respecting Hull docks, - - 163
 Report of the same relative to sundry matters concerning the Hull docks, &c. - - 168

WORKINGTON HARBOUR.

Report of J. Smeaton upon the improvement of the harbour of Workington, - - 170
 Second report upon the same, - - 175

PLYMOUTH YARD.

Report of J. Smeaton upon the defective works in Plymouth yard, - - 177

BRIDLINGTON PIERS.

Report of J. Smeaton upon the state of the Bridlington piers; with the most probable means of preserving the same from the destruction of the worm, - - 187

SUNDERLAND PIER.

Report of J. Smeaton upon Mr. Shout's plan for rebuilding and extending the old pier of the harbour of Sunderland, - - 194

TINMOUTH HARBOUR.

Report of J. Smeaton on Timmouth harbour, - - 196

SCARBOROUGH PIER.

Letter to the Commissioners of Scarborough pier, - - 198

SHIELDS DOCK.

Estimate for lengthening the dock at North Shields - - 200

TREW-

CONTENTS.

Page

TREWARDRETH HARBOUR.

Report of J. Smeaton upon the question of a harbour in the bay of Trewardreth, - - 204

JERSEY HARBOURS.

Report of J. Smeaton upon the harbours of St. Helliers, and St. Aubin, - - 206

QUEEN'S FERRY SHIPPING PLACES.

Report of John Smeaton upon the shipping places at Queen's Ferry, in the Firth of Forth, - - 215

EDINBURGH BRIDGE.

Report of Messrs. Smeaton, Adam, and Baxter concerning the bridge of Edinburgh, - - 218
 Report of J. Smeaton, on several matters referred to him concerning the bridge of Edinburgh, - - 223
 Report of J. Smeaton upon the state and improvement of the water service of Edinburgh, - - 228

COLDSTREAM BRIDGE.

Papers relating to Coldstream bridge, - - 235

NEWCASTLE BRIDGE.

Report of J. Smeaton concerning the state of that part of Tyne bridge betwixt Newcastle and Gateshead, in the county of Durham, - - 252
 Report of J. Smeaton on the state of that part of Tyne bridge belonging to the town of Newcastle, - - 254
 Minutes of a view of Newcastle bridge, - - 257
 Report of J. Smeaton and J. Wooler relative to Tyne bridge, - - 260

HEXHAM BRIDGE.

Reports, &c. relating to Hexham bridge, - - 267

BERWICK BRIDGE.

Report of J. Smeaton upon the state of Berwick bridge, from a view thereof, - - 345

BANFF BRIDGE.

Estimate for building a bridge over the river Doveran, near Banff, - - 349
 Explanation of the manner of laying the foundations for the bridge of Banff, - - 351
 Explanation of the center for the bridge of Banff, - - 352

DUMBALLOCH BRIDGE.

Estimate for building a bridge over the river Bewlie, at Dumballoch, - - 355

BRAAN BRIDGE.

Estimate for building a bridge over the river Conon, at the Boat of Braan, - - 357

ALTGRAN

CONTENTS.

Page

ALTGRAN BRIDGE.

Estimate for building a bridge over the river Altgran, near above the present wood bridge,	-	-	359
--	---	---	-----

BRIDGES AT BEWLIE, CONON, ALTGRAN, &c.

Report of J. Smeaton upon sundry matters referred to him,	-	-	360
Pier or landing-place at Portleich,	-	-	362
Estimate for building a pier or landing-place at Portleich, upon the bay of Cromartie,	-	-	363
The mills and watercourse to the mills of Miltown of Newtarbet,	-	-	364
Estimate for a new dam head and watercourse for the mills of Miltown of Newtarbet,	-	-	366
The piers or landing-places at the ferry of Inverbreakie,	-	-	367
Estimate for the landing-places at the ferry of Inverbreakie,	-	-	369

SUTTON BRIDGE.

Report of J. Smeaton upon the design for a new bridge over the river Hull, near Sutton,	-	-	370
---	---	---	-----

WALTON BRIDGE.

Report of J. Smeaton upon the state of Walton bridge,	-	-	371
Estimate for building a brick superstructure upon the present piers, with the addition of a new pier in the middle of the river, for a bridge over the river Thames at Walton in Surrey,	-	-	376

HARRATON BRIDGE.

Estimate for a scaffold bridge on stone pillars, at Harraton upon the river Wear,	-	-	378
Estimate of the stone arch and additional pier,	-	-	379
Method of founding and building the stonework of Harraton bridge,	-	-	380
Construction of the masonry for Harraton bridge,	-	-	381

BRIDGE AT CARLTON FERRY.

Mr. Smeaton's opinion concerning the building of a bridge over the river Aire at Carlton ferry,	-	-	383
On Mr. Carr's design for Carlton bridge,	-	-	ibid.

MONTROSE BRIDGE.

Estimate of a bridge according to a sketch proposed for crossing the South Esk from the Inch Breck to the Fort Hill at Montrose,	-	-	385
--	---	---	-----

TINMOUTH BARRACKS.

Letter to the Honourable Mr. St. John, concerning Tinmouth barracks,	-	-	387
--	---	---	-----

LEEDS INFIRMARY.

Letter to the Committee of Leeds infirmary,	-	-	393
---	---	---	-----

EARL

CONTENTS.

Page

EARL OF EGREMONT'S COALS.

Report of J. Smeaton, respecting the practicability of exporting coals from the estates of Bransty, Birkby, and Aspatria, in the county of Cumberland,	-	-	396
--	---	---	-----

ROSEVEERN AND OWERS LIGHTHOUSES.

Concerning the island of Roseveern,	-	-	404
Concerning the erection of a lighthouse upon the Owers,	-	-	406

COAL MEASURES.

An account of the measures of coals at Newcastle and London, and of the customary measures in the parish of Whitkirk, and adjacent parishes,	-	-	410
--	---	---	-----

POZZELANA MORTAR.

Directions for preparing, making, and using pozzelana mortar, by J. Smeaton,	-	-	414
--	---	---	-----



REPORTS, &c.

KING'S LYNN HARBOUR.

The REPORT of JOHN SMEATON, Engineer, relative to the Harbour of
Lynn in Norfolk.

THE Matters to be reported upon as given me in charge by the Magistrates of *Lynn*, were principally the following :

First, The preservation of vessels lying in the harbour of *Lynn*, from the annoyance of winds and waves ; not only from the sea, but from the broad river above the town, when the wind happens to be in that quarter, and also from the raging tides that often accompany them, and drive the Vessels from their moorings :

Secondly, The preservation of the banks of the river, and more especially those near the town, from the action of the winds and seas, accompanied also with too rapid a tide.

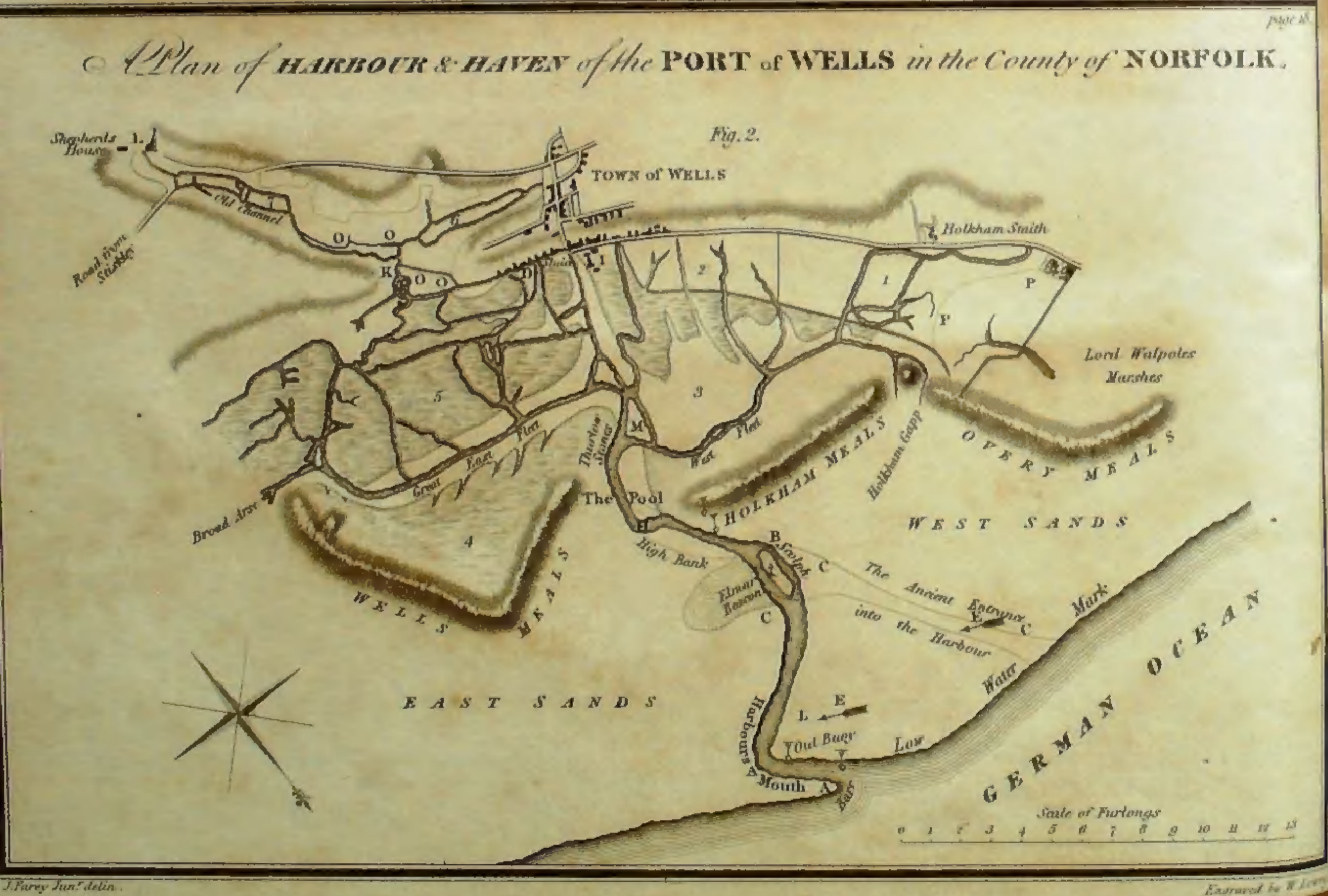
The better to enable me to acquit myself upon these subjects, I carefully examined the channel of the river *Ouse*, from the roads near the *Ferris Beacon* to *German's Bridge* ; and also the banks thereupon, and more particularly those within two miles of the town

Note.—In the plan of the harbour, Fig. 1. Plate 1. the figures in the channel shew the depths in feet and half feet at low water ; the other figures shew the height of the ponds, lower shores, salt marshes, and banks above low water mark.

VOL. III.

B

of



of *Lynn*. I have also carefully viewed and examined the circumstances attending the said river, from *German's Bridge* to *Denver Sluice*; so far as they appeared to me to have any relation to the business before-mentioned.

In the course of these enquiries, I had the pleasure to find, that the channel of the river, and particularly that part to seaward, not only from the accounts of the pilots who attended me, but from my own remarks, compared with former accounts and reports, was, at the time of those observations, *viz.* in the month of *July 1766*, in as good condition as it had been known for many years; and in fact without any material cause of complaint. That a bar had formed itself in the upper mouth of the west channel, and that the current at low water was wholly confined to the east channel, which had in consequence proportionally improved.

This is indeed a very material change in the state of the channel and harbour for the better; the contrary condition having been complained of for years past, *viz.* the choaking of the harbour and channel to seaward with sands, and the great tendency of the current to take the west channel instead of the east; which latter (as it seems) was that, which, according to the unanimous opinion of all those who have reported upon it, was the desirable channel to be maintained, and if possible improved; the doing of which has been the subject of much projection and altercation: but as nothing appears to have been done in consequence, but that Nature has very kindly brought matters into a more desirable state, it seems of the utmost importance to propose nothing for execution, that shall counteract her intentions; nor while we are relieving one evil induce a greater.

According to all accounts, the point below the crutch on the east side of the river, called at present *Nottingham Point*, projected much further to the westward: and another point of land on the west side of the river, below *North Lynn*, but above the said *Nottingham Point* according to the course of the river, projected further eastward; so that, to a person standing upon the quay called the *Common Staith*, at *Lynn*, the sea was land locked by these two points; but that now, by the gradual wear of one or both of them, an observer standing at the same place, will, at high water, see the sea considerably open between the said points; and the wind being in that or nearly that direction, that is, betwixt N. N. W. and N. N. E. and a strong spring tide of flood, the ships are apt to ride very unquietly that lie within the point formed by the *Common Staith* and the *Ball*, which may now be reckoned the port of *Lynn*, and where the ships chiefly lie to be loaded and unloaded from the merchants' yards.

This

This evil I find has been complained of for many years; and in the year 1741, a scheme was offered by Mr. *John Rosewell*; which was to build jetties from these two points so as to produce the same land lock as formerly: and this he imagined would not only redress this immediate grievance, of too much swell running into the harbour, but also others at that time also greatly complained of; that is, obstruction by sand, too shallow a channel, a high bar in the east channel, and too great a diversion of the current into the west channel.

That those jetties might be of some use in checking the swell of the sea, cannot be denied; but the ill effects they were likely to have by encreasing the tendency of the out channel to the westward, is set forth with great justness and spirit, in a small pamphlet, published in the year 1742, entitled, *Some thoughts on Mr. Rosewell's and other Schemes, now proposed for amending Lynn Channel and Harbour**; which, as I suppose it in every ones hands, to save repetition, I recommend to a re-perusal, from the beginning to and including the 9th page. And indeed Mr. *Rosewell's* reasoning, if such it can be called, concerning the improvement of the east channel by means of those jetties, has not been more solidly refuted by the author above referred to, than it has since been by Nature herself: for it seems very manifest, that in proportion as the points, particularly *Nottingham Point*, have been worn away, the channel has tended more eastward; and has improved in proportion as the west channel has decayed, which must be expected from an union of the two forces. As therefore the maintenance of the channel out to sea, in the good condition in which I found it, I look upon as a *primary* consideration; I entirely agree with the author before-mentioned, that it would be a dangerous expedient to reinstate the two points above-mentioned, by the building of jetties: on the contrary, I am of opinion, that where a channel must be maintained through a vast mass of sand, capable of shifting by winds, seas, currents, and every temporary impression of power thereon, that the more directly the waters make their passage out to sea the better.

Nor am I very clear, that the reinstating of the points would entirely cure the evil at present complained of; they being at too great a distance from the interior harbour, and must necessarily be placed at so considerable a distance from each other, that unless the entry was entirely spoilt, I apprehend the seas would still find the way within the heads: and in so long a fetch to the place where the ships lie, would gather and still disturb them at their moorings.

Nor can they be of much use in checking the too great indraught of the tides, at present complained of; for the passage between them must be very narrow to produce a

* This pamphlet is anonymous, but I since understand was wrote by Mr. *Elstob*. See Appendix to this Report.
sensible

fenfible effect, and in proportion as it was contracted, it would wear deeper, and thereby still admit nearly the same quantity of water to pass. Yet, if they could be so made as to check the raging tides, they would check the moderate ones too; and I believe all agree in opinion, that in the situation of *Lynn* harbour, the greater the efflux, which in great measure depends upon the influx, the better channel may be expected to be maintained: too great tides may be a partial and temporary evil, but it appears to me in the present case a fault on the right side; and it seems that in this, as well as many affairs of human life, the judgment consists in chusing *the least of two evils*.

I cannot however agree in recommending the expedient mentioned in the latter part of the pamphlet above quoted; that is, damming up the old river at the west point, and cutting a new one through the land, down to the road; for this, if not made equal with the mean capacity of the old river, would check the influx of the tides; and if so made, would be a most monstrous expense, and at last the event would be uncertain; for by producing an alteration in the set of the currents, without the mouth thereof, it perhaps is out of the power of human foresight to say with certainty, that (after so great an expense) some bar or impediment might not be thrown up, producing an equal obstruction to those then complained of; but thanks to Nature for relieving us from the necessity of so chargeable an expedient, and giving us the opportunity of *knowing when we are well*.

The simple point of view, that in my opinion is necessary to be attended to for the preservation of the channel, is to do nothing *materially* to affect the indraught of the tides, or to diminish the quantity of fresh waters coming down the river from above: as to the rest, it must be left to Nature, and though in such a multitude of acting forces and disturbing causes, the goodness of the channel must by turns become *better and worse*; yet the grand principles of preservation being maintained in all the vigour possible, after a wrong turn happens a right one will succeed, as experience has shewn to be the case; at least leave Nature to herself while tending right, it is time enough to help her when we are sure she is going wrong.

It is observable, that the point formed by the *Common Staith*, and running out betwixt that and *Common Staith Lane*, may be considered as the jetty, whereby the ships lying above in the interior harbour, are ultimately defended from the swell coming in from the sea; and it is only the swell that gets round this point from the sea that affects the shipping; for in fact, the ships that lie in the channel of the river, between the *Purfleet* and the *Ball*, are land locked by this point. This jetty has very much the appearance of having been artificially carried out as well as defended by stone wharfing for this very purpose.

purpose. The river is however still a furlong, that is, 220 yards, wide at this point, according to the plan; the channel lies over to the opposite shore, where it is ten or twelve feet deep at low water, whereas it gradually shallows towards the *Lynn* side, leaving the ground dry at low water for above a chain in breadth.

If I were obliged to recommend something in the *jetty way*, it would be to run out this wharf about a chain further, that is, twenty-two yards, being one-tenth of the whole width of the river. I am very clear that such a projection, immediately before the shipping, would afford more protection than six times as much work done at the two points below; which are at the mean distance of a mile and half; and this without being attended with any ill effect upon the channel below. The only objection that I see to this scheme is, that by narrowing the channel in this the narrowest place, it would in some measure check the influx of the tides; and throw the water more powerfully upon the opposite shore, just below the ferry, the defences of which are already too weak: but if this bank were effectually defended by a sufficient body of rubble stone, applied in such a way as I shall mention, when I come to speak upon the defence of the banks, the effect would be to ~~scour out a channel so much deeper in this place, as, by creating an equal section,~~ would furnish the same quantity of tide water as at present, and probably might deepen the channel on the *Lynn* side; at least something might be done to intice it to act in that manner.

It is observable, that at the end of *Common Staith Lane* there is a considerable prominence of rubbish that has gradually been formed, and that something of the same kind has been thrown out partly from the lanes, and partly from the houses, quite away to the *Purfleet*, and higher: I look upon it, that it is owing to this body of rubbish, that the channel of the river edges over so soon to the west side; if this body of rubbish were dug away as near to the buildings as can be done with safety, and taken down to or below low-water mark as far as the *Common Staith*; that the ebb tides, accompanied with the land floods, would improve the channel, and enable the ships to lie not only lower down, but closer in, and thereby more effectually shelter them from the seas, which would be broken off by the *Common Staith* point; and this is a step that I would recommend; whatever becomes of the proposition of an extension of that point.

I come now to the defence of the shipping when the wind is at S. W. or westerly; that is, when it blows right down the broad river which extends above the town; and with this view it obviously occurs, that if a jetty or break-water were carried out upon the sands from the point above *Old Lynn*, this would in some degree shelter the shipping that lie from the *Ball* downwards: but yet, unless the jetty be extended from A to B in the plan, that

that is, the length of a furlong, or 220 yards, the vessels lying at or near the *Ball* will still be exposed almost as much as before: on the other hand, this work will throw the current more forcibly into the bite or great hollow opposite this point, where the water sets already too hard, and is making daily depredations. I would therefore beg leave to suggest, that as no ship lying from the *Ball* downward, can be subject to a direct fetch of more than a mile in length; and since in this length no great swell can be raised, but only a short chopping sea or windwash, which would signify little, independent of the force of the wind and a strong tide of ebb, both which must remain; I say, I would put a query, whether it would not be advisable at once to endeavour to encrease the security of the vessels in the harbour, by improving their moorings; which I apprehend might be done by putting down a row of strong *dolphins* on the west side of the channel in the middle of the river; and continuing the line lower down, and increasing in number those that are on the east side. This measure, independent of every thing else, would be a great security against disturbance, both from land and sea. However, if the magistrates are inclined to begin a jetty or break-water from the S. W. point in or near the direction specified in the plan, in order to try the effects of it, I would not be understood to discourage the attempt; and if not carried beyond the limits there specified, I apprehend any ill effects that it might have upon the opposite bank might be guarded against. It may be begun with rice and rubble stones, and afterwards by sinking old vessels; or continued with the former materials, as shall appear in the execution best to answer the end.

I come now to the subject of the banks: and on this head, as I have already declared that my opinion is in general, to discourage all attempts to prevent the free influx and efflux of the tides and land waters, in order to preserve the channel out to sea in the most effectual manner, upon which both the navigation and drainage dependent on the *Ouse* entirely hinge; nothing remains to be done with the banks, but to make them stout enough and high enough to stand against all extremes: my business will therefore be, to shew how this is to be effected. To give directions about the particular parts would be endless, and will be the proper business of the surveyor, who shall be entrusted with the execution thereof; I shall therefore content myself with shewing the general principles, which will easily be applied by the judicious artist to the particular cases.

In the first place, I entirely disapprove of all jetties built into the stream, as a defence for saving the banks or foreshores from the action of the water, as I am convinced from many observations that they have a direct contrary tendency; for they seldom fail of producing a deep pit, either opposite to, or on the downstream side of the jetty, which tends

tends to undermine the banks, and even the jetty itself; so that thereby the *rent is made worse*.

Whatever works are attempted for the preservation of the foot or banks of foreshores, when too hard a *set* of the water tends to undermine them, ought to be disposed parallel, or according to the direction of the stream; so that the water, instead of being stopped or thrown off, shall glide gently by, with the least interruption possible; for thereby the water gets away with the least possible action upon the banks, and consequently wears them or their defences the least. For this reason all angles and sudden turns are to be avoided as much as may be, and where a turn must be made, as very frequently happens, let it be made with as easy a sweep as possible, keeping it as near as may be the same with the natural, that is, the general *bend* of the river, cutting or rounding off all small sudden turns, angles or extuberances, which may happen in the general sweep; which directions will hold, as well for forming the base and middle lines of the artificial banks themselves, as for preserving the foot of the natural foreshores, whereon the other is founded. To act otherwise is to oppose a natural current, and to oppose a natural current is to give it something whereon it may incessantly act, towards the destruction of the opposed work; which in the case of banks and their defences, is to do something contrary to the very intent of doing it.

This doctrine cannot be better illustrated than by the two great jetties, in the turn above the *Ball-fleet*, opposite and just below which are five and six fathom water; whereas the natural bottom or depth is not more than as many feet. By this means their foundations are sapped, as well as the adjoining banks, which in consequence must be subject to very expensive repairs, as the bite of the river will grow deeper on every alteration.

This is also the case with a number of jetties on the west side of the river below the ferry: to say the truth, I scarcely ever saw an instance where this sort of works, when applied as a defence to the banks, did not do mischief; it would be very well that they were all removed, or if this is thought too much expense, at least never more to be repaired in their present form.

Where the sides of a river or foreshores grind away by too great stress of water, the most infallible, secure, and lasting method of doing it is, after the sudden extuberances and irregularities of the curve are taken off as low as the water will admit of by hand, to line up the foot with rubble stones, thrown in promiscuously, so as to form

form their own natural slope against the shore, till they appear above water, at low water. This being done for the whole length of the galled place, with the regularity before described; and being further supplied with a fresh quantity after a settlement has happened, in consequence of succeeding great tides and floods; will prove a lasting security against further depredations at the foot; and the foot being well secured, Nature will, in most cases, where there is room to do it, form of herself such a natural slope to neap tide high-water-mark, as will need no artificial defence. The chalk and clodlime rubble that is brought down the river, seems a very good material to be employed in this way, but the rubble of any stone that will bear wet and dry will do, which can be procured cheapest; the larger and more irregular, both in point of shape and size, the better.

The same defence, where stone is wanting, may be procured by the application of stakes and rice; but disposed, as before directed, even and parallel to the stream*, without jettings or extuberances; but nothing can be done with these materials comparable to rubble stones, on account both of want of weight and duration.

It may possibly be objected, that a sufficient quantity of rubble stones, to secure the foot of the banks and foreshores in this manner, will be expensive; and in some cases possibly it may; but it must be considered, that here will be no expensive tide-works, with a number of men, and that there will be very little additional charge beyond that of bringing down the stones; but in preference to all methods that are in themselves ineffectual, the cheapest way is to do nothing.

The base of the bank and foreshores being secured as above described, it has already been said, that where there is room enough, Nature will herself form a slope upon the foreshores up to the high-water-mark of neap tides, which will be of itself a sufficient defence against waves and currents; and where there is no want of room to form a sufficient slope above the neap tide high-water-mark to the top of the bank, there is no better way than to slope and turf it over, in the manner that has already been put in practice, but above and below the town of *Lynn*; and also on the other side of the water. I can give no better directions than these specimens will afford, which seem done with great judgment; only that, instead of using any wood at the foot of the turf about neap tide high-water-mark, I would advise to rely wholly upon a *lay* of rubble stone; and if some of it is broken small so as to fill up the interstices of the larger pieces, this will form a more complete union between the rubble and the turf, than if composed of large stones only.

* The ends outward, and a little inclining down stream.

Where the artificial banks stand steep upon the foreshores, I observe that the practice about *Lynn* has been to defend them by a boarded wharfing. This at first seems to promise much security; but experience has proved that this is only *outside*: and if we consider the action of the waves upon it, we shall find this method not at all calculated to sustain their shocks for any length of time, the very union of the parts being the cause of their destruction.

If the sea dashes against the end of a faggot or a stone, these having no solid connection with their neighbours, the impression goes no further; but the tremors raised in one part of a boarded wharfing is communicated to the whole, or to a large area; which, accompanied with the great shocks that must ensue when a considerable part of the surface is struck together, these agitations by little and little shake and loosen the earth behind, which by the rise and fall of the tides is by degrees washed out at the foot and through the crevices, which brings the whole to ruin. This, accompanied with the speedy decay of all wood work exposed to wet and dry, makes it seem to me quite eligible totally to discard this method in all future repairs. In lieu whereof I would recommend the following: wherever the foreshores are not broad enough from low water to neap tide high-water-mark, to stand by a natural slope, I would advise them to be reduced to a slope of two to one; that is, to batter two feet to one foot perpendicular; and this being covered a foot thick with rubble stone of all sizes bedded together, and footed upon the rubble, supposed to be thrown in to support the ground under low-water-mark, will, as I have often experienced, make a very lasting defence, and is capable of great resistance in all ordinary cases; but if exposed to the waves of the open sea, the cover must be increased in weight and thickness. This method will answer the end, if the batter is three to five, or even one to one; but the latter I would not recommend without extreme necessity.

With respect to the upper part of the bank, from the high-water-mark of neap tides, to the high-water-mark of the equinoctial spring tides; I would, in all cases where it is possible, shift back the banks, till they will admit of the slope and turf method above referred to; but if this be not possible, to continue the same batter as the foreshore, and to face the artificial banks with stone in the same manner as already described.

I do not know of any security against *inundations*, in a country that is defended by banks, otherwise than by making those banks, not only sufficiently strong, but high enough to sustain the greatest extreams, without being overflowed: and it is from *experience alone*, that these extreams are to be learnt.

The greatest extream of a flood or tide that has been known at *Lynn*, appears to have been one on the second of *December* 1763, when the water flowed one inch deep in the computing house of Mr. *Elfdon* of *Lynn*, and left a very visible mark, which he shewed me. This mark should at high-water of some spring-tide, be transferred to the Custom-house, or some public place near the river, to which recourse may constantly be had. Though this is the largest tide we know of, yet there are accounts of several tides within a few inches as high as this; I do not therefore look upon the banks to be safe, unless they are proof against such another tide as this; and to this, as a standard, I would constantly refer: I cannot, however, look upon them as *proof*, unless they are made up at least one foot above the level of this mark, and maintained, after settlements, at the height of half a foot above the same. It is not, however, necessary, to preserve the same slope above the high-water-mark of equinoctial spring-tides to the extreamest height, as below that mark; because they will but seldom come to that height; yet when they do, they must be *sufficient*, or they answer not the end.

In order to this, they ought to be three feet at least broad at the extream height; and at least three times as much broader at the level of the equinoctial spring-tide mark, as the extream height exceeds that height. The artificial banks below that mark should be at least four times as much broader, in their base or seat, upon the natural level of the ground, as the perpendicular height of the said extream tide-mark is above the natural level of the ground, whereon each part of the said bank respectively stands. These proportions will be very sufficient in the neighbourhood of *Lynn*, where the earth is good; but where the earth is loose, sandy or moory, the bases or seats and tops should be respectively broader.

These are the best methods that I know of putting the town and country in a state of security; every other attempt to lessen the tides themselves will not only be vain and fruitless; but even, if effected, hurtful to the general drainage and navigation of the country.

If the expense be objected to of making up the banks in this manner, I answer; that if we take the compass of a few years, it will be a great saving: but since this is the only permanent and secure method that I know of; if it is not worth while to put the properties into a state of security, then the proprietors must be contented to possess them in a state of insecurity:

After having declared it as my opinion, that every attempt to check the free influx and efflux of the tides (that is, while it remains an open river) is likely to be hurtful to the

scour of the sea channel; it seems natural to be asked, if I do not look upon *Denver Sluice* in this light? I answer, that *Denver Sluice* is much too far up from the out-fall to work any considerable effect either way; but that the *natural* effect of it, as well as the hundred foot drain, so far as they operate on the harbour of *Lynn*, and sea channel below, must be rather beneficial; as may be demonstrated from a circumstance mentioned in *Badslade's* history, page 46, where, speaking of the river *Ouse*, he says, "The low-water-mark up the river is much lower in neap than in spring-tides; whereas down to seaward, the low-water-mark of a spring-tide is lower than that of a neap." This being the case, (which is not a peculiarity of this river,) it is evident that the spring-tide of flood, in the remote parts, could not get back again the same tide; but, instead of returning back, spent itself up the river, and in the fens, before that sluice was built; it is therefore, at that length, more useful to check the tide of flood, in order to give it a better recoil, than to suffer it to spend itself in the fens at the spring-tides, and languidly to return in the neaps; without power in itself to operate, or to co-operate with such a tide as would give it power. The cause, therefore, of the universal silting of the channel of the *Ouse*, after the first erection of *Denver Sluice*, and cutting the hundred foot river, so universally and loudly complained of, must be sought from other sources, than a *natural tendency* of these works to produce this effect: but as this will lead me into a fresh and large field of matter, not immediately conducing to the business in hand, I shall forbear the pursuit of this subject any further at present.

I cannot conclude my Report without observing, that it strikes me, that the surest, and I may add the cheapest, way of putting the ships into a state of *perfect* security, would be by building wet docks in the manner of *Liverpool*; for which, the situation of *Lynn* seems to afford a noble opportunity, particularly in the flat ground below the block-house.

J. SMEATON.

Austhorpe,
14th September 1767.

APPENDIX.

Containing an Extract from a Pamphlet printed in the Year 1742, said to be wrote by Mr. Elstobb; intituled, Some Thoughts on Mr. Rosewell's and other Schemes, now proposed for amending Lynn Channel and Harbour; in a Letter to the Merchants, Owners, and Masters of Ships, belonging to the said Place.

GENTLEMEN,

THE present state of your channel is now not only become the common topic of conversation, but also the laudable care of the magistracy, whose ready disposition to do service to the town, is evidently manifested by the early steps they have taken in this affair; in consequence of which, Mr. Rosewell, by order of the honourable the commissioners of the navy, has lately inspected the harbour and channel to seaward, down as low as the road, and has proposed a method, to remedy the evils, which he observed at present to attend them, and to prevent their growing bad for the future.

But as I think the remedy he proposes, will not remove the evils he complains of, but will rather increase them; so I cannot forbear giving you my sentiments thereupon, tho' without any design of depreciating that gentleman, who I doubt not is sufficiently judicious in things of this kind. But as he came an entire stranger to the place; and as I am informed, took but a transient view of it, and formed most of his sentiments, from the information of people, prejudiced in favour of particular notions and opinions concerning the thing, it is not to be wondered at, that he is so far wide of the matter.

His opinion it seems is, that the badness of the channel to seaward, is owing to a bar of sand, lately grown up cross the east channel, about three miles below the crutch-point. And he says, he is informed, that the said crutch-point on the east, and the point on the west side of the harbour's mouth, formerly landlocked each other, by which means the harbour was preserved in a great measure from the fury of the north-west winds, and flood tides, was rendered safe, and the channel maintained deep and good; but by the continual force of the said winds and tides against the west point, and by the violent action and force of the south-west winds and ebb-tides, against the crutch-point, on the east side, both these points of land are now much shortened, and the harbour laid more open; so that the fury of the north-west winds tears down the marches, endangers the banks, and threatens the ruin of some of the lands on the east side of the river, between the block-house and the crutch; the consequence of which may be (he says) the entire loss of the harbour. Besides, since the points are thus become open, (I think he says), it occasions the flood to form an eddy, by which means the silt subsides, and has formed the bar which he so much complains of.

The

The remedy therefore which he proposes is, to erect two jetties, or wooden piers, one on the west-point, to stretch over to the eastward; and the other on the crutch-point, to stretch itself to the westward; and so to landlock the harbour, as it formerly has been.

By this means (says he) the harbour will be preserved from the violence of the north-west winds and flood tides, will be rendered safe and quiet, the east-channel recovered and the bar be scoured away.

This, gentlemen, is his opinion, and the remedy he proposes. And now, with all due submission, I shall beg leave to give you my sentiments thereon.

'Tis to be observed, that in the present state of the harbour and channel, there are but two evils which have fallen under his notice.

The first is a bar of sand on the east channel, three miles below these points, which he supposes to be lately grown up, and formed by means of an eddy in the flood tides, occasioned by the shortening or opening of the said points. But how the alteration of the state of these points could any way form such an eddy as to occasion a bank of sand in the channel, at three miles distance, is to me quite unconceivable. Besides, the bar is no new formed thing — he supposes, but is of old standing, as is well known to the gentlemen navigators; tho' 'tis not always in the same state, but often fluctuating and changing: being sometimes higher, sometimes lower, according as seasons have proved wet or dry, and the quantities of the ebbs and back-waters have been greater or less. Thus, in some very wet seasons, it has been almost worn away, and the channel for a while maintained good; and in dry seasons again, it grows up, and the channel becomes bad; which has lately been the state of it, tho' now by the increase of the back-waters 'tis already much mended. However, let the duration of it, and the formation of it be as they will, the removal of it is the thing.

And this I believe every one will agree must be effected, by the ebbs and back-waters, which should be convey'd as entirely, unitedly, and directly to it as possible, so that they may exert their whole undiminished force and power thereon, without meeting with any stops or impediments in their way. For the force of water in scouring away a sand, or deepening a channel, is always proportional to the quantity acting in a given time, and the vigour or force with which every equal part of that quantity does act. Thus, for instance, if a tun of water was to pass over a sand in a minute's time, and every gallon of that water exercised a force on that sand, which may be represented by 1 or unity, then the whole force exercised in a minute's time upon that sand, may be represented or expressed by

by the number 252. But if the quantity of the water acting in the same time be doubled, and the force with which every gallon acts, be doubled also, as it will be if the velocity of the current be doubled, then the force which the water exercises upon the sand in a minute's time will be four fold what it was before, and in this case may be expressed by the number 1008.

What then can we think of this gentleman's jetties, which, instead of conveying the back-waters and ebbs directly to the bar without obstruction, must necessarily divert them from it, and turn them over to the westward, giving them such a course as will direct them much more into the west channel, and cause them to strike more directly against the breast sand than at present, and so both lessen the quantity acting, and also the force with which every proportional part does act; so that if the bar increases and grows upon us now, we may then expect the decay of the east channel will be much accelerated; for sure 'tis not a little absurd to imagine, that turning the course of the ebb-water more to the westward, can promote the removal of a sand which lies in the east channel, or any way deepen or mend that. Too much of the ebb-water does already go down the west-channel, which lies too directly in its present course; but if its direction be changed still more to the westward, as it certainly will be by these jetties, then the principal part of the ebb-water will be turned into that channel, and other slide ways, which can afford it a passage to the westward; and the east channel will be almost deserted, and left almost dry every ebb, and consequently in a little time would choak up, and be entirely lost.

So far then is the method this gentleman proposes from being a certain remedy to the east channel, that in all probability it will be the utter destruction of it. And thus much for the first evil he complains of.

The other evil is, the washing away of the marshes, and the danger of drowning the lands on the east side.

This (I shall beg leave to observe) is a thing which more immediately concerns the land-owners than this corporation. The security of their estates is certainly as much their own proper concern, as the security of those on the west side is the proper concern of the owners of them. But (says this gentleman) *the drowning of these lands will be the ruin of your harbour.*

This I must confess I do by no means apprehend. Suppose that two or three hundred acres of these lands were every tide laid under water, not one gallon the less water would flow up the river than does at this present, and all the waters, which would then cover these

these lands in the time of flood, would be an additional quantity to return in the time of ebb, which would certainly very much help to scour away the bar, and maintain a good channel. But suppose that the security of the harbour does depend upon the preservation of these lands, are these jetties like to be effectual for that purpose? I conceive not. 'Tis true, they will lessen the beat of the tides during the time of high-water, which by the opening of these points, when the north-west wind blows, is now very great, and washes away the surface, and turf of the land very fast; this I say would be in a great measure prevented. But then the flood-tide would be carried continually and directly into the crutch-bite, and so would the ebb also; and by the continual and violent action of both, the lower shores would be ground away, and the bite extended more and more to the eastward, and the lands and banks will be effectually ruined by the undermining of the shores, as by the wash and beat of the waters upon the surface; tho' perhaps not altogether in so short a time.

Now, as I think this will certainly be the consequence of this scheme, so I thought it an incumbent duty to apprize you of it, that you, whose interests depend upon the preservation of the navigation of this port, may make proper representations against it.

I know some gentlemen are mightily alarmed at the wearing away and opening of the two foremention'd points, as if the ruin of the harbour must immediately ensue, and as if the goodness of the channel entirely depended upon the projecting or extending of these points. But it may be remembered, that some years ago, while *Denver* sluice was standing, and the reception of the flood lessen'd, and the back-waters prevented from coming down, the quantity of the ebbs was then so small, that it was all carried off by the west-channel, and the east-channel was so deserted, that at low water it was left almost dry, which made it soon grow so shallow, that at the time of high water, there was not water sufficient for any loaden ships, all which were forced to go round at the back of the sands, and come through the west channel up to town; and at that time these points were both far extended, and landlocked the harbour. 'Tis therefore very evident, that the goodness of the channel does not depend upon the extension of these points, nor do I apprehend that there is such imminent danger from the opening of them, as some are inclined to think.

The channel is now in as good a state as it commonly has been in for some years. And if we should in a little time have a continued wet season, which may happen, it will quickly be much mended. And I think it is much the better way, to trust to nature for a remedy, than to execute at a great expense such schemes as in all probability will be very pernicious and hurtful to the channel.

Some

Some gentlemen it seems do plainly discover the impropriety of Mr. Roswell's scheme, but yet think something ought to be done for the preservation of the lands, and the amendment of the channel, and therefore are for erecting a jetty cross the crutch-bite, all along the east side, towards the block-house; and another jetty on the west-point, to extend this point more over to the eastward.

The first, certainly, so long as it stands, if made sufficiently, high, will be a great security to the marshes, and lands on the east side, and would prevent both flood and ebb from encroaching on that side, and likewise assist them in scouring away that pernicious point of sand, which extends itself from the west point, so far over to the eastward, into the crutch-bite, for though the turf and vegetable soil at the west point are much washed away and shortened, the sand stretching from that point is by that means much lengthened, and determines both the flood and ebb more over to the eastward than before; and so far will it be from doing service to the channel, to extend that point, that if the vegetable soil was only secured in its present limitations, and the point of sand intirely scoured away, it would certainly be much better for the channel, for then the ebb would not be so inclinable to go down the west channel, but would proceed more directly to the bar, and act upon it with much greater force than now, and consequently keep it lower, and maintain the east channel better; and then perhaps the west channel might gradually grow up. And happy would it be for *Lynn*, if that channel was intirely stopped up, for it is the quantity of ebb that goes down that channel, that so weakens the current in the east channel, that instead of scouring away the points of sand which project into it, it is stopped and retarded by them, and formed into vortices and eddies, which throw more and more silt upon them, and in some places (as at the bar) extend them quite cross the channel; for it is by this means, and by the flood-tide coming up the west channel, and forming an eddy at its entrance into the east channel, that the bar so much complained of is formed: for it is observable that this bar lies not far below the mouth of the west channel, just about the place where one might expect such eddies would occasion it.

A jetty therefore at the west point, seems to me quite wrong, and I think will be very hurtful. If therefore a jetty must be erected, I would advise it, not upon the west point, but about a furlong to the westward of it, to extend itself to the northward, along the east part of the breast sand. This would allow the ebb to scour away the sand, that stretches from the west point and turn it more directly down the east channel, towards the bar; and would at the same time very much secure the east side from the violence of the westerly and north-west winds, and be a great shelter to the harbour too from these winds.

And

And if the west channel could be stopped up, by the sinking of old hulks loaded with stones, or any other means, so that the ebbs might be prevented from taking their course that way, we might then have great hopes of maintaining the east channel, in a much better state than it has ever yet been in.

But as some gentlemen are apt to imagine, that a jetty on the west point, by turning the ebb-water more over to the eastward, will direct it more into the east channel, it must be acknowledged that it would have this effect, if this channel were situate to the eastward of that point. But the east channel itself is situate far to the westward of that point, and consequently the more the ebb is carried to the eastward by the jetty on its south side, the more westerly must be its direction on its north side, to arrive at that channel; and when once it has received this westerly direction, the west channel and other shade ways lie so fair to receive it, that in all probability very little of it will go down the east channel.

The way then to direct it down the east channel, is not to turn it more to the east at the west point: ~~it going far much to the eastward at that place already;~~ but the way must be to let that point of sand wear away, that it may take its course more in a direct line for that channel. Some may object, that the wearing away of that point will lay the harbour more open, and make it more turbulent and unsafe than at present. But in answer to this, a jetty from the west marsh, to extend northward, along the east part of the breast sand, will in a great measure prevent that. However, it is to be observed, that the security of the harbour, and the goodness of the channel, are two different things, and what procures one, may be pernicious to the other. The goodness of the channel will be promoted by the quantity of water that comes into it, and flows through it, but the greater the quantity of water, the greater the agitation, and the more turbulent. On the contrary, the less the quantity of water, the less the agitation, and the quieter the harbour, but then the worse the channel. When such works are undertaken, therefore, the end and purpose should be well considered, and things inconsistent in themselves should not be pursued at the same time.

However, it is not to be expected, that these, or any other means, can render the channel constantly and unchangeably good, so long as its course lies betwixt and amongst such loose and moveable sands. A rage of winds and tides, or an extraordinary time, either of drought or rain, will occasion great alterations in it, sometimes for the better and sometimes for the worse, because even when the back waters are the strongest, and so the most likely to preserve a good channel, they will sometimes scour away the sands in one place, and let them drop in another place, where they may be more prejudicial to the channel than before; and thus will the state of the channel be always liable to changes and alterations.

WELLS HARBOUR.

(See the Plan, Plate I. of this volume, Fig. 2.)

The REPORT of JOHN SMEATON, Engineer, upon the State and Condition of *Wells Harbour* in the County of *Norfolk*, and how far the same may be affected by the Imbankment of the *Slade Marshes*.

HAVING carefully inspected the present Condition of the Harbour of Wells in the county of *Norfolk*, and the *Slade Marshes*, and other premises, the object of a suit wherein Sir Martin Brown Folkes Baronet, and Robert Hales Esq. were plaintiffs, against George Chad Esq. and other defendants, and having also carefully inspected the several Plans and Papers that have been produced in evidence in the said cause, the following facts drawn from my own view of the premises, and in part from the evidence produced, appear to me to be very well ascertained and agreed upon.

1st. That the harbour of Wells has of late years grown into a worse state than it formerly was in, and particularly since the imbankments that took place in and about the year 1719; and,

2d. That for remedy of the complaints that then subsisted in the harbour, in the year 1738, a work was constructed that had the name of Freestone's Sluice, so called from the projector or builder thereof, whose name was *Freestone*.

3d. That this work had a beneficial effect in scouring away the mud and sand that annoyed the Harbour and channel from the mouth of the said sluice, down as far as the Pool.

4th. That at that time, that part of the channel called the *Pool* was so deep, that at low water two or three tiers of vessels could lie afloat, and swing round.

5th. That in the year 1758, the last imbankment was erected, which is the matter now complained of, and is the object of the present suit.

6th. That

6th. That the extent of ground inclosed, and defended by the said imbankment, is nearly 17 acres in the East Marshes, and 47 in the Slade Marshes, together making about 64 acres, besides and interspersed in which are creeks formerly and now containing water to the amount of about three acres, making altogether a surface of about 67 acres, or thereabouts.

7th. That besides the above, there is not only a much greater quantity of imbanked lands, which was chiefly taken in about the year 1719, but still a much greater quantity than all the imbanked land put together, still remaining unimbanked, over all which the spring tides usually flowed before the imbankment, but the neap tides rarely, and which now is the case with the greatest part of the unimbanked marshes.

8th. That no fresh water river makes its way to sea through the channel of the harbour of Wells, nor indeed any considerable quantity of fresh water of any denomination; and that not only the channel that forms the harbour, but the several branches and creeks into which it is divided (as is particularly distinguished in the map made by Beiderman under the direction of Mr. Mylne) are all supplied with sea water on tide of flood, which reflowing back to the sea on tide of ebb, thereby forms a back water and produces a scour that tends to keep the channel of the harbour open.

9th. That in the year 1765, Freestone's Sluice having been originally constructed in a slight manner with fascines, flakes, piles, &c. the mouth thereof was so much widened, that its effect having been for some time past greatly impaired, another was built upon a new site, which when erected, reproduced the same effect, as to clearing the harbour and channel down to the Pool.

10th. That the sluice of 1765 which had been constructed with greater strength and care than that of Freestone, though upon the same model, in the year 1777 was found to have been nearly destroyed by worms; on which occasion Mr. Wooler was called in to advise the commissioners, who reported his advice to build a new sluice in a new situation, upon a new construction, and with such materials as the worm could not touch.

11th. That on account of the expense estimated by Mr. Wooler at £2,000, this work was not undertaken, but in lieu thereof, proceedings were gone into that terminated in the present litigation; on supposition on the part of the commissioners, the defendants, that the taking down the East Marsh Bank, whereby the tides would be readmitted upon the surface of the 67 acres before mentioned, would reduce the state and condition of the harbour in every respect, or in all the most material respects, to what it was before the erection of that Bank in 1758.

12th. That however, the Sluice since Mr. Wooler's report has been repaired, and it appeared at the time of my view to be of the same construction that it had formerly been, according

according to its description, and tending to produce the same effect, which it is reported to have formerly done.

13th. That during the whole interval since Freestone's Sluice was first constructed in the year 1749, to the present time, the operation of the sluice has constantly been (when in order) nearly the same, viz. that of clearing and keeping in the same good condition nearly all that part of the harbour and channel that lies between the mouth of the sluice, and the upper or south end of the Pool.

14th. That during a period of years since the year 1749, the Pool has been filling up, or growing shallower, inasmuch, that at low water, at the time of my view, there was not above six feet water.

15th. It further appears from evidence, that for a long period of years preceding all the imbankments herein mentioned, the outfall or mouth of the channel of the harbour has lain very considerably more to the westward than at present, and that it has from time to time changed more to the east.

16th. That formerly, that is, within the compass of 20 years, the direction of the channel out to sea was N. W. and that at that time the flow of the tide being in the direction of the channel, during all the time of tide of flood, it was very easy with a proper wind to bring vessels from the sea through this channel into the pool and harbour.

17th. But that since the channel has come more to the east, and the direction gradually veered about, so as to have come now to a N. E. or N. E. by N. direction, as it was at the time of my view, it is a fact, that whenever the tide has risen above the surface of the Broad Sands, the tide still keeping its former direction from N. W. to S. E. drives the vessels across the channel upon the eastern bank or sand, and therefore without a strong leading wind vessels cannot enter without danger, and in fact since these changes have taken place, many ships have been lost, notwithstanding the skill of the pilots, to the no small disadvantage of and disparagement to the port.

18th. That the distance from the quay to the outfall of the channel is at present betwixt three and four miles, and that the channel both now lies and ever has lain, through large broad open sands, from the northward or out end of the pool to its outfall into the sea, which sand being perfectly clean, and free from all particles that might create tenacity, when dried by the sun is capable of being blown by the wind, and moved by the common agitation of the sea, and very considerable changes are wrought by the action of the sea in great storms and tempests; and that this is the description of the sands in general that lie many miles extended on this coast.

19th. That

19th. That the breadth of this sand, or distance from the pool to low water mark, has considerably increased within the memory of man.

20th. That the channel from the Shelf without the north part of the pool to the sea has now as much, and about the same draught of water or flow of tide at high water, as it has been known to have in man's memory.

21st. That the port of Wells is of great consequence not only from its situation with respect to the surrounding country, but also from the traffick settled in the place, and therefore that nothing ought to be done that can be of real detriment thereto.

I have thrown together the above leading facts not only for my own ease in composition, by avoiding more tedious definitions, but that from this general view of the state of facts, I may be the more readily followed in my reasonings thereupon.

From the above there naturally arise the following questions:

1st. What is the natural cause of the decay of the harbour of Wells?

2d. Whether the imbankment in question made in the year 1758 have materially contributed thereto?

3d. Whether the removal of that imbankment will contribute to a material amendment thereof?

Question the first.—What is the natural cause of the decay of the harbour of Wells from what it has been in former times?

To have a clear and comprehensive view of the cause of decay, it will be necessary to shew the natural causes by which the port of Wells has been formed.

We are all apprised that notwithstanding the annual downfalls of rain and snow upon the land, which run into the sea in every part of the habitable globe, the quantity of water contained in the sea is never the greater; and this may reasonably be expected when we consider that the exhalations which form those rains and snows, are chiefly raised from the sea by the power of the sun and winds.

The floods and torrents that make their way from the surface of the land, in consequence of the rains and snows, take along with them great quantities of clayey, earthy, and sandy matter (intermixed with many other kinds of matter, which it is needless here to enumerate)

enumerate) down into the channels of the rivers, and are by the violence of the torrents carried to the sea, and there in appearance dispersed.—These kinds of matter, not being capable of being raised again, and returned back to the land, as the water is, it necessarily follows that the quantity of sandy and earthy matter that is deposited in the sea, is in a continual though apparently very slow state of increase, and by the constant flux of the tides, and the agitation of the winds, those materials so deposited are capable of being removed from the parts adjacent to their entry into the sea, not only to the neighbouring, but even to very distant parts; and though the remarkable quantity of sandy soil in the county of Norfolk may in part account for the vast quantities of sands upon the coast thereof, extending as it were in one continued chain from the coast of Lincolnshire, very much infesting the great bay between the two counties called the *wash*, and still extending coastways far beyond the port of Wells, even to Cromer, as I have been informed, yet it is by no means necessary to suppose that they have *all*, or in the greatest measure, proceeded from the land of the two counties, to the coasts of which they now lie contiguous; they may as well have proceeded from parts far more distant, and that brought hither by the incessant action of the winds and tides, they find a place better adapted to their reception and repose than those from whence they came; and indeed it may also be as well supposed that they may in *part* have come from those coasts which by the particular set of the wind and tides have been *washing* for ages past, as to suppose that they all proceed from the high lands of any place or kingdom whatsoever.

It is however of no consequence to our argument to point out *whence* they came; it is sufficient that they have come, and that being here deposited, and finding it a place where they are less liable to be carried away than they were to be brought hither, the quantity upon the whole must increase, and since there appears no power of nature by which they can be returned to the high grounds, or coasts from whence they were brought, it must follow that they must continue to increase, till some contrary power of Nature shall take place that we are not acquainted with, or the place of their reception become entirely filled.

It follows then that the attachment of sandy and earthy matter to this coast is in a *progressive state of increase*, which it is as much out of any human power to prevent, as it is to prevent the sandy and earthy matter from being washed down from the high grounds into the sea.

We need not therefore extend our views further to be enabled to see clearly, that in some former age, that is, in some state of the progression of this work of Nature, there was a time, when nothing more than a naked sand lay against the bare coast of the elevated

elevated ground upon which the town of Wells now stands, which — may suppose similar to that which now lies between *Wells Mills* or *Marram Hills* and the low water at sea, which being upon one regular decline, the tide water can flow and reflow over the surface without channel or creek; and in this state, as there would be no harbour, there would not on that account be need of a town: but let the breadth of the sand gradually increase to double, and then the declivity would become too small for the tidal water left by the flood to make its retreat so as to keep pace in its return with the ebb at sea; and therefore a body of water being thus left behind, and having a sensible declivity towards the sea, would naturally make its way into the lowest flades, and there cut a *gully*, which (if not formed gradually — may be supposed) would soon be enlarged by the influx and efflux of the tide; and thereby a scour would be produced through this passage enough to keep it open, in a degree sufficient to let the water in and out, till it became so quiet as in a manner to cease the operation of scouring; but the breadth of the sands gradually increasing, a greater body and surface of water will want a passage, and the power of scouring will increase with it; the gully will therefore by the same slow degrees enlarge to a *creek*, or *fleet* as it is here called, and lesser ones will be formed to conduct the water more readily into the larger.

The natural progress attending this operation is, that the parts of the sand furthest distant from low water, being less liable to agitation from winds and tides, the sand intermixed with the finer particles of earthy and clayey matter brought in by the tides, are the most readily and quietly lodged there; and particularly the earthy and clayey particles will find a resting place, which binding the sand together, the whole will continue to rise, till at a certain height, and in consequence of a certain length of time of absence of the salt water each tide, and exposure to the sun and air, the surface becomes fitted for vegetation, and by degrees will grow a certain species of grass, and become a salt marsh; the grass again entangling and locking up the earthy matter, will cause it to continue to rise, and in an increased ratio, as the water upon the plain grass surfaces becomes more shallow, and in consequence more still, and free from the agitation of external disturbing causes.

During this period, as the marshes have increased in height, they have also increased in breadth, and in consequence a greater body of water will be left upon them; the gullies and creeks therefore, as they multiplied in number with the increase of breadth, the larger ones would increase in size and depth, and if all were ultimately collected into one, as has been the case with the channel of Wells Harbour, the scour would be sufficient to maintain a channel through which vessels might be brought from the sea, and thus

thus an useful Harbour would be formed, which would increase in depth and utility by the continuance of the forming powers, but yet, only to a *certain degree*.

I have said that, as the marshes increased in breadth and height, more water wanting a passage to the sea would be left upon them; and this, so far as regards breadth, is self-evident; but as the increase of height diminishes the depth of water upon them at high water, that the quantity left behind upon the whole will be greater, needs some explanation. In respect to this, it is obvious to every one who views the subject, that while the depth of water upon the marshes is considerable, the water makes its way to sea by settling gradually, and passes off in the nearest direction over the marsh surfaces, without having any need for the gullies and creeks as drains; it is therefore perhaps only the last half foot that may need the gullies; which, however, being limited to some certain thickness (be it half a foot more or less), and this thickness much less than the depth at high water, the quantity so left will be in proportion to the quantity of surface; and the number of gullies, being also in proportion to surface, the aggregate of the whole and the scour thereof in the last channel will also be proportionably increased; it is likewise remarked, that in fact, the scour is not very material till the water upon the marshes has ebbed near their surface, that is, until it is just retreating into the gullies, when the principal scour begins.

Under these circumstances, the scour would increase and consequently the goodness of the harbour of Wells would naturally improve, while the neap tides covered the surface of the marshes; but as the same progression would in time cause the surface of the salt marshes to rise above the ordinary neap tides, the scour would then begin to diminish, because, being not only deprived of the efflux of the water from the grass surfaces into the gullies a number of times in a fortnight, the scour of these gullies becoming immediately less, they would themselves begin to choak up, and contain less *following* water; and therefore, in both respects, the scour being diminished in each particular gully, the scour of the whole must diminish.

It is most probable that this harbour, from the slow progress of the changes above specified, may have continued in a very flourishing state for a long term of years, reaching backward beyond all record; though it is likely that for a part of that time it may have been in reality in a state of decay, and which we will now shew will naturally result from the same progression of causes that carried it to its *maturity*; so that after having clearly seen from what natural causes the Harbour has been produced out of the sea without a fresh water river to give it birth, we shall then see the natural causes to which its *decay* must be attributed.

From

From what has been laid down, it will appear most manifest that the rising or elevation of the surface of the salt marshes, by a fresh accession of sea mud which they will acquire more or less every time they are overflowed, will not stop at the *neap tides*, but will gradually rise higher and higher towards the high water of spring tides; and if after that they were only to be overflowed in the great springs or raging tides, yet as every one of these tides will deposit something, they will ultimately be shut up at the height of the extreme high water, though no *imbankment* whatever was to take place; and this will also happen in succession to the gullies, creeks, &c.

For ■ the surface of these marshes rises higher and higher from the neap towards the spring tide mark, they will be less and less often overflowed, and the gullies made by the reflux of the tidal water from their surface will become less and less capacious, and in consequence of a want of reflow, the creeks will suffer the same fate, and lastly, the *fleets* and *main channel*: But as the tide water flowing in through the channel, fleets, creeks, and gullies, to the several extremities of its branches must flow back the same way, it is the extremities that will be first landed up, because every part betwixt such extremity and the sea will have water beyond it to flow over or through it, and thereby producing some degree of a scour, will keep open a passage either greater or less, while any water can get beyond it; and hence we must expect, that the parts of the channel most distant from the sea will be those that in a state of nature will soonest lose their depth and capacity, till progressively, from the extremities towards the sea, the gullies, creeks, fleets, and main channel will become solid land: and so far it appears from testimony, that long before the imbankation in the year 1758, nature had got on so far in its progress in the decay of Wells Harbour, that it was much complained of; and the upper part between the quay and the pool was got so bad, that the goods were in general lightered up to the quay, and that for remedy thereof, Freestone's Sluice was built in the year 1749, which produced a good effect in clearing that part of the Harbour. As then it plainly appears from the preceding discourse, that the progression of nature has no tendency to cure the evils complained of, but still to increase them, they are in consequence incapable of any remedy, except what can be applied by the ingenuity and labour of man.

We now come to the 2d question, whether the imbankment made in 1758 has materially contributed to the decay of the harbour of Wells?

From what has preceded it has been clearly shewn, that as the keeping open and maintaining the channel entirely depends upon the reflow of the tide water, or *back water* as it is called, whatever cuts off and diminishes this, must be a detriment to the scour, and consequently to the maintenance of the channel; I therefore do not hesitate in saying that

that all the imbankments both east and west of the town of Wells, the water received upon the surfaces of which, and into their gullies and creeks, used to make its way back to the sea by the channel of Wells Harbour, must have co-operated with the progression of nature, and thereby tended to bring on more speedily a general want of depth, which, as it has been already remarked, will be first perceived at those parts of the tidal flow the most remote from the sea; nay, we may go so far as to say, that if a bucket of water were taken up in the upper part of Wells Harbour, and not suffered to reflow, it might prevent the displacing of some particle of matter that had been lodged therein by some preceding tide. In this sentiment I suppose every able engineer and skilful person that has viewed the premises will join as a *general opinion*, but though very true as a general sentiment, yet the whole merit of the question depends upon the *quantum*, the *how much* damage could result from those artificial means; and as in this it appears that the opinion of different men have widely differed, I will proceed to state my own with all the precision and clearness I am able.

Now, if the breadth of the sands continue upon the increase, we must conclude that the reflux of the tidal water from the whole surface covered continues, upon the whole, if not greater, as great as formerly, and therefore will maintain as good a channel to sea at the outfall at low water; nor does it appear from any testimony that, from the scalp to the outfall of the channel into the sea, there is a less depth at high water than formerly existed; the complaints and appearance of a diminution of depth of the harbour are from the lower or north end of the Pool upwards towards the town. It appears therefore, that the upper part of the channel that lies contiguous to the main land is *landing up*, and that in fact the harbour is moving *towards the sea*.

It does not appear from testimony that the filling up of the Pool, or its growing shallower, so that ships cannot now lay afloat or swing round in tiers as they used to do at low water, has been a matter very much complained of till after the imbankment of 1758; but this does not disprove that the fundamental cause thereof may have existed long before the ill effects have become sensible to seamen, and those using the harbour; and indeed it clearly appears to me, that the filling up of the Pool sooner or later, is only a link in the general chain of causes that must have operated so as to produce this effect, whether any imbankment had been made or not.

To see this clearly we have nothing to do but to advert to the situation of the Pool, for it begins just below or about where the *West Fleet* falls into the main channel. This Fleet received the drainage and back waters from the *Holkham* marshes, which appear to have been anciently of much greater extent than at present, and consequently the back water or
reflow

reflow must have been very considerable from this great extent of surface, as well as that which still lies unembanked, and which being joined by the great reflow of back water from the East Fleet, the Little Fleet, and the Haven Creek, with all their extensive dependencies, must have formed a great and rapid scour of back water, especially when it is adverted to, that it is confined within a narrow compass between the Holkham and the Wells Marram Hills or Miel; we must therefore expect no less than a very deep channel in this extent, well deserving the name of *The Pool*. And that this confinement of the whole water both of flood and ebb, between the hills just mentioned, gave an additional scouring power to the tidal water, appears further from this, that the Pool never appeared to be of further extent northwards till this opening between the hills being cleared, the tidal water having an opportunity of escaping on tide of ebb over the broad sands lying without those points, its force became dissipated, and the great and sudden scour ceased, that caused this deep water even in that age when the whole scour was in its greatest degree of strength and perfection, and the depth and goodness of the harbour consequent upon it. But whenever (as has been shewn) the scour beyond it became diminished by the rising of the marshes above the high water of *neap tides*, the depth of the pool would begin to diminish, for the scours would then be unable to ~~scour out the sands from so great a depth~~ before, that would be continually brought in by the N. W. winds at *Holkham Gap*, from the broad sands lying to the north thereof, and then by the West Fleet carried down into the Pool.

Nor is the Holkham Gap the only source from whence the sands brought down by the West Fleet might be collected; for I look upon it that the inside, that is the south side, of the Holkham Miel Hills, is continually melted down by winds and rains into the great area or bay drained by the West Fleet, while those hills are continually supplied with fresh sand blown up by the force of the N. and N. W. winds upon and over them, from the broad sands that are yearly extending more and more from thence to the northwards into the sea; the highest parts of which broad sands being frequently left at neap tides long enough to be dried by the sun, are by the wind capable of being blown up in great quantities, so as to raise and continue those hills far above the high water of any tides whatever, though composed of nothing more than a blown sand from the sea, somewhat united by the bent grass that grows up through the same, of which there are very many examples in various parts of the kingdom.

In that age when the scour at the pool was in its full perfection, it is probable that it was very much deeper than it has ever been reported by any testimony or record now extant, and so long as it continued deep enough for the purposes of shipping, there would be no cause for complaint; and till it became too shallow for ships to swing at low water,
its

its diminution of depth would be little regarded. There is therefore no doubt but that the Pool was growing shallower long before the imbankment of Holkham marshes, as a considerable length of time must have elapsed between the period when Holkham imbanked marshes were just rising above the high water of neap tides, and their acquiring the height at which they were imbanked; and which height I judge was not materially different from the present.

When the ground of Holkham marshes was become high enough for embankment, the natural scour arising therefrom was diminished from what it had been, and though they had not been imbanked, would have been still much less at this day. Yet so great a surface as 560 acres, the drainage of which plainly appears by the map to have made its way out to sea by the West Fleet, being cut off at once in the year 1719, and 108 acres more in the year 1721, the whole of this together amounting to 668 acres, may reasonably be presumed to have had some sensible operation in accelerating the effects that nature in her progression would afterwards have brought on, though no artificial imbankment had been made; but it by no means follows, that the effects of those imbankments must be *immediately* perceived at the Pool. This by slow and imperceptible degrees must be supposed going on as before, and by less slow but yet imperceptible degrees might be going on after; yet this must be attended to, that in proportion as the scour of the west fleet was diminished by the loss of the imbanked marshes, the power of the same scour would be diminished to carry down the sand continually into the pool, as it before used to do, so that till the great bay that still continues to be drained by the west fleet, as it were gorged with sand from Holkham Gap and Holkham Miels, it would not be brought down in so great quantities each tide as before the Holkham imbankment; and therefore as it appears that the whole progress of this business is very slow, it must be expected to have been a series of years between the *cause* from the Holkham imbankment and the *effect* becoming more perceivable in the landing up of the pool; and in case this necessary period of years extended from the year 1720 to the year 1758, that is near 40 years, at which time the last imbankment was made, then those would become *cotemporaneous* events, and it would be no wonder that the united effects of the Holkham imbankment, and that of the Church marshes in the year 1719; and also of the West marshes of Wells in the year 1720, making in the whole 572 acres, together with the additional loss of scour from the surface of the salt marshes which yet remain unimbanked to the amount of between 15 and 16 hundred acres, the drainage of all which have their outfall through the Pool; I say it would be no wonder if under these circumstances the united effects tending to land up the pool should be charged to the account of the imbankment made in the year 1758, if it were possible to suppose that the imbankment made that year of 64 acres could have a sensible effect, for the object of this imbankment amounted to no more than $\frac{1}{10}$ part of the

the whole quantity concerned in producing it; when it remains *problematical*, whether the effect of the 572 acres taken in before, which is near nine times as much, would *alone* have been sensible, if the effects thereof had not been mixed with what might have arisen from nature's simple progression, in case its operation had been no ways disturbed by that of art.

I find myself therefore forced by fair induction to infer, that though strictly speaking the effect of every thing that has an effect must be *something*, yet that the imbankment of the salt marshes in the year 1758, could not in any sensible degree capable of measure or estimation contribute to the landing up of the pool.

The effect thereof upon the outward part of the channel must be still more remote; for it does not appear from any principles of observation, or practice, that when a back water, even assisted by a fresh water river ever so large, makes its way through broad moveable sands, it has any tendency in itself to make its way out to sea in this direction more than in that. ~~The natural tendency of water is to make its way in whatever direction it finds the greatest declivity; and if that happen to be in the shortest direction,~~ it has no natural tendency to gain a longer course, as that would lessen the declivity: If therefore water is found going in a course that is not the shortest, we may conclude (and on examining we always find) that this longer course is owing to the intervention of some object so placed, that the water can have in that particular part a more speedy descent in a direction different from that which would form the shortest line of the whole descent; and from causes of this kind a stream may have a course in every possible degree meandering that we frequently observe in nature.

If therefore the course of the out-fall channel to sea at low water was in a north-west direction through the broad sands, as it seems very well attested to have been in former times; and if at those times the course of the channel corresponded with the general set of the tides upon the coast, so that vessels going in or out through the out-fall channel were not driven out of their proper course by a set of the tide *cross* the channel, as is said to be the case at present; it may be imputed to some of those lucky causes that operated in favour of those times, as no strength of back water alone could have a natural tendency to produce this effect: And if the accidental operation of contrary causes, as suppose winds and tides, either considered alone, or as acting in correspondence with the regular progression of nature already described, has brought the direction of the out channel into a situation less favourable to navigation than it used to be formerly, at the same time that it has produced a shorter course for it to sea, than it would have if returned to its former direction; I am therefore clearly of opinion, that no increase of back water, even if aided by a fresh water river, if artificially brought down

down this channel, would ever cause it to return to its former north western direction, so as to disembody itself, at a place considerably more west than the present outfall.

I do not however mean to say that it *cannot return*, but that if it does, it must be in virtue of causes operating in a contrary way to those which have brought the mouth of the channel from the westward towards the east, and not in virtue of any change that can be expected to be wrought simply by an increase of back water; for that would be to make a more rapid stream have a tendency to go a longer journey to sea in preference to a shorter.

It is alledged indeed, that, from a general increase of the breadth of sands upon the coast, it is now further from the north end of the pool to sea than it used formerly to be, but this must be understood of the straight line from the said point to low water, without regard to the direction of the channel. For though the present channel should be as long from the pool to the sea, or longer than formerly; yet from the general increase of the breadth of the sands, were the channel to go much further westward than at present, it would have a longer course to sea at low water.

What may have been the particular causes that have brought the mouth of the channel more to the east than formerly, does not appear material to the present question; but to give satisfaction as far as I am able, I will hazard the following conjecture: It is an observation universally agreed upon, that the N. W. winds make the highest tides in the whole German Ocean; the N. W. winds, then, accompanied by *higher* tides will produce more agitation, and consequently carry the sands from the N. W. eastward, in a greater degree than that in which equal winds from the south-east accompanied by lesser tides will bring them back; and according to the local direction of the coast here, they directly tend to accumulate them upon the shore toward the N. E. If this is a true solution, as I apprehended it to be, there seems not the least likelihood that the direction of the channel should ever be permanently removed to the west, but rather that it should be carried further to the eastward than it now is; and what gives strength to the above conjecture is, an observation I had the opportunity of making upon my view, viz. that the outfall channel of the harbour of Blakeney (a few miles eastward of Wells, and situated in a similar manner, in regard to the course of its outfall channel through the broad sands) has shifted also more to the eastward than it was, by above half a mile in the last seven years, as appeared from the marks I was shewn for its entry at that period, compared with its present place; notwithstanding that Blakeney Channel has two large fresh water rivulets that make their way together through this channel to its no small advantage towards keeping it open. The place also of the outfall at low water of the east discharge from the salt water creeks called Wareham Deeps, I was shewn to have removed its place further eastward, than it was at Michaelmas last, by several

several hundred yards, and that chiefly within the compass of the preceding three weeks to my view, during which very strong north westerly winds had prevailed. Wareham Deeps lie betwixt Blakeney Outfall Channel, and that of Wells.

There is one thing more respecting the outfall channel of Wells Harbour that it may be proper to touch upon, and that is, the bar that is described in Beiderman's map to lie across the mouth of the channel so as to be prejudicial to the entry of vessels; but after what has been said, be the impediment arising from hence greater or less, it cannot be imputed to the imbankment of marshes; but to the sport of winds and seas at the place, which will further appear from this circumstance; that when I was examining this place at dead low water of a spring tide, viz. the 15th of March last, I did not observe there was any appearance of a bar, the course of the channel being right out to sea, at N. E. by N. by the compass, yet in another season it may probably return.

Hence, from the above premises, I must entirely acquit the whole of the imbankments, from having been in any degree contributory to the disagreeable effects arising from the change of the outfall channel of Wells Harbour.

What I have further to say, will come most naturally under the third and last question proposed.

Question the 3d, Whether the removal of the imbankment of the Slade Marshes will contribute to any material amendment of Wells Harbour?

It appears clearly from what has preceded, that the progressional operation of nature, which originally formed the harbour of Wells and brought it to maturity, has also occasioned it to grow more and more into a state of decay; and will finally close it up, and convert into firm ground, fit for arable purposes, and those of pasturage, the very spot where ships have rode at anchor; and that this being the progression of nature cannot be countervailed in any degree, but by the industry, art, and hand of man.

It is a fact well established by evidence, that, previous to the erection of Freestone's Sluice in 1749, the upper parts of the harbour, as far down as the pool, had got landed up to that degree, that the shipping, which chiefly laid in the pool, were obliged to have a great part of their ladings brought and carried to and from the town by lighters. That upon the erection of Freestone's Sluice (which as far as appears was the very first attempt in this harbour to counteract the operations of nature by art this

rude and simple piece of art succeeded so far as in a very great measure if not effectually to relieve the distress that they then laboured under; viz. that of the quays being in great measure inaccessible to shipping; a construction so rude, that though bearing the name of a sluice, it would seem as if it had been one of the first attempts to obtain relief by art, before sluices had been invented; and hence we may infer, that if this did so much, what might have been effected by a *real sluice*, built upon a proper and regular construction. This sluice however was attended with a beneficial effect so long as it lasted; and when it went to decay, the part of the harbour affected by it reverted to its former state.

In the year 1765 they again set about to relieve themselves, not by building a sluice upon a better plan, but by erecting a new one upon the same plan, upon fresh ground, with better, and as they expected more durable materials: And this sluice reproduced afresh the effect of the former, which has indeed continued to this day. But in the year 1777 it was discovered to be defective and liable to fail on account of the timber wherewith it was built being eaten with a sea worm, unknown in these parts before, that had attacked it. On this occasion Mr. Wooler, an ingenious engineer, very competent to the business, was called in, who very judiciously advised, not only to build a new sluice upon a new foundation, and of more durable materials, but of a different construction, so as to give a better effect to the issuing waters, as the best means for preventing the harbour going to decay. This salutary advice however appears to have been rejected by the commissioners of the harbour, on account of the expense; in lieu thereof, they adopted another expedient, which, as they thought, was liable to be attended with less expense, and quite as effectual. Having observed, on popular grounds, that many things had gone wrong with the harbour since the last imbankment in 1758, they supposed that they were the effects of that measure; and inferred that by removing the cause, the effects would cease, and every thing come right again. It shall therefore now be my business fairly and fully to examine what foundation there was, or may be, for such a supposition.

As the commissioners of the harbour I presume did not pretend to professional skill in *civil engineering*, they could be no otherways blameable for misjudging in a matter dependent on that art, than that had they fully examined the question upon the like popular grounds, which are alike intelligible to all men, they would have seen there was no just foundation for their expectations. For in the year 1749 the waters of the Slade Marshes had not been interrupted in their operation, and yet this harbour was become choaked, and had got into so bad a state, as to call aloud for immediate relief; what reason then had they to expect it in the year 1778, when, according to the natural progression, every thing had got worse?

In 1758 Freestone's Sluice had gone to decay, and the harbour was speedily reverting to the state in which it had been before the year 1749. Now had the operation of the Slade Marsh waters been observed to have been of any material consequence, the imbankation of 1758 would have been opposed and objected to at the time, which yet does not appear; and had any bad effects appeared to have arisen from the imbankation in the year 1768, that is ten years after the imbankment, and three years after the rebuilding of the sluice, when an application to Parliament was necessary to get fresh powers to defray the expenses incurred by that erection, &c., it would have been natural to endeavour to get some equivalent for the damage, or at least, as sluice-building must then appear to be the best expedient, to have got powers over the grounds in the unimbanked marshes to enable them to erect such proper additional works, ■ might from time to time be necessary; and which might have been expected upon easy terms, and without depending on leave being always given in case any damage to the harbour had been felt or apprehended from the imbankment, because the more amicable terms subsisted at that time between Sir John Turner and the commissioners, the less he could have opposed or denied so reasonable a request. But yet nothing of this appears, or indeed any other, till after the year 1777, when Mr. Wooler had reported that a proper sluice was "of the utmost importance towards keeping the channel of the harbour open, and clear of the sands that are constantly brought in by the tides;" and that such a work would probably cost the sum of £2,000. These I say are popular arguments, which as every one can equally see the force of them, ought to have induced the commissioners to seek relief, by pursuing means of reducing Mr. Wooler's advice to execution, rather than deliver the Slade Marshes once more to the empire of the salt waters: but as a professional man, I conceive it will be expected from me to give a direct proof of the efficacy of this idea; of this I shall therefore endeavour to acquit myself in the clearest manner possible.

Respecting that part of the last imbanked marshes that lies west of the ancient imbankments, comprehending 16 acres, it is evidently of no more account than any other 16 acres that lie immediately upon the haven creek, and whose waters immediately ebb within the tide, without passing through the sluice; that is, they would have no other effect in scouring than as making a part of 1770 acres, the water from which makes its way to sea by the Pool; but with respect to the forty-seven acres that lie eastward of the ancient imbankment, and are called the Slade, or Slade Marshes, they appear to me to have a different import.

The reason why the waters passing the sluice have a greater effect in scouring than those which return to sea without passing the sluice, is, because by the contracted opening of the passage of the sluice, the waters that lie in the creeks behind it are detained from ebbing so quickly as they otherwise would have done; that is, their numerous mouths when always open, reduced

reduced the level of the water contained therein, to nearly the same level as that of the water in the main channel of the harbour, being stopped by dams made across and united by cross passages into one, and the mouth of this being contracted by the work called the sluice, a body of water is held back in these creeks, as reservoirs, which not being able to escape so fast as the tide ebbs in the main channel, it follows, that a body of water by these means is vended upon, and after the half ebb, which discharging itself into the harbour's creek, forms a scour when the depth is so much lessened as to operate with power in grinding the bottom, which otherwise would have been so languid as not to have stirred a grain of sand or mud, in which case its effect would be little or nothing. This artificial scour thus procured, in some degree imitates the effect of a fresh water river, which in these situations is very greatly beneficial, not from any virtue there is in fresh water preferable to salt in these cases (namely thing rather less on account of its less specific weight), but from its having a fall from the land, and proceeding therefrom continually it not only strengthens the ebb, but running to sea at low water when the fall being greatest, and the sandy bottom exposed to its action, it continues to work at a time when it can operate to the best advantage; and when the ordinary current of a river is assisted by extraordinary land floods and freshes from downfalls of rain and snow, and this operating at low water, when, as just remarked, the fall is the greatest, in such cases it is capable of producing extraordinary effects, and of keeping a harbour continually open with a channel of a given magnitude, though loaded with sands in any possible degree: for a fresh water river has this peculiar advantage, that at the same time that it strengthens the scouring power of the ebb, it operates most forcibly at low water, when there is the least to obstruct its operation; it opposes the tide of flood from the sea, and thereby prevents its bringing so much sand and silt into the harbour as otherwise it would.

The defect therefore of this sluice of Wells is, that though it retains the waters so as to be behind the general ebb, and thereby strengthens the latter part of it considerably; yet being at low water all spent, when the greatest good might otherwise be obtained, it loses that good effect which would be had from a fresh water river, or from a proper sluice; that is, one that will retain the water wholly till a proper time of tide, and then being let go in one collected body, is capable in a short space of time of producing marvellous effects; and yet I should not expect such a sluice either to clear the Pool to the depth it had fifty years since, or to carry the outfall channel to the Northwest.

By sluices of this kind, which are the only expedients art has found that is comparable to a river, the greatest part of the sea ports in Flanders and Holland are kept open, and under

under circumstances more unfavourable than the port of Wells, many of which are built not only with great expense, but to the useful part, but with much magnificence, as relying upon the durable utility of their construction. Those of the Wells traders who have occasion to visit the port of Ostend, so much resorted to at the present time, will see a remarkable example thereof in the grand Sluice of Ostend re-erected in the year 1755.

The Slade then consisting of 47 acres (or somewhat less, on account of the high grounds inclosed therewith), it appears to me might derive some occasional advantage in respect of scouring, from the very circumstance of their situation lying behind the ancient imbankment; insomuch that what is alledged by some of the witnesses may at some particular time or times be true; videlicet, that when the tide was spent at the town, it came down from the Slade.

It seems well attested, and from the nature of the thing (as it appeared on my view) must be the case, that the surface of the Slade never used to be overflowed, but in extreme spring tides, here called *rages*, and the condition of it in growing rushes and other vegetables peculiar to fenny fresh waters before its imbankment, shews this to be the general case; and this would naturally and necessarily arise from the very contracted channel and opening left between the N. E. bank of the ancient imbankment and the high land so narrow, that it does not appear, except in such cases, that there would be a sufficiency of time at high water for the whole surface of the Slade, considered as a pond, to fill any thing near the utmost height of the sea; but yet whatever water was at such times brought upon it, would, upon the same principles as the sluice, be left behind, and retained by the same narrow passages, so as to require possibly the whole of the succeeding low water entirely to vend it; but then it will follow, that by how much it was the longer in vending, it would come down the more leisurely, and toward the latter part of it the more dribbling, in proportion as its channel to let it out grew more contracted by the surface of the water being lower therein: so that although it might at those times come down in good quantity in the first quarter's ebb, where meeting the remains of the waters from the 16 acres of Slade Marsh, and other waters from the unimbanked marshes, that still fall into the haven creek without passing the sluice, and might make a sensible increase of the current; yet as this must greatly fall off after the top waters were gone, and give but little aid in the latter part of the ebb, when it was most wanted, must equally appear plain and clear. But yet whatever good effect might be ascribed to the water from the Slade, or in reality it might have, when it could operate in the manner I have pointed out, yet as it appears from equal testimony that those rages happen but seldom (four or five times in a year), they could be of no material benefit, because their power of scouring and grinding the bottom,

bottom, inasmuch as the sea is incessantly bringing in a fresh accession of sand, silt, and mud, must be in proportion to their frequency, so that if it were to be supposed (what it does not appear to me reasonable to admit), that the effect of the Slade waters was when they happened even equal with that of the sluice, yet the sluice, if we put the neap tides out of the account, operating 365 good tides in a year, and those but five, the benefit could only be as 70 to 1; an effect so small, that, when mixed with many others, could not be perceived; and though in the eye of reason every thing that operates at all must have an effect, yet it clearly appears to me that the effect to be expected either by the shutting up or opening those marshes in the manner they were before the imbankments in 1758*, could procure no such beneficial effect upon the harbour as to prevent the necessity of supporting and continuing the sluice, or even to be of any measurable or estimable degree or value; and that this extraneous idea of the small utility to be derived or expected from the Slade marsh waters, is in reality the true one, is proved by the facts already stated; viz. that before the year 1749 they had proved *totally ineffectual*, and had always proved so ever since when the sluice was out of order. I must therefore conclude in the sentiment of Mr. Mylne, that whoever would find a cause for the alteration of the course of the out-channel, for the filling up of the Pool, for the landing up of the harbour, channel, or creek, and in general the decaying state of the harbour of Wells, must seek some cause far more extensive than the imbankment of the Slade marshes in the year 1758, and the remedy from human industry and art in something more powerful and better adapted than any of the sluices there applied appears to have been.

London,
4th May 1782.

J. SMEATON.

* I say in the manner they were before the year 1758, that is, when there was no bank at all; because if a partial breach was made in the bank, the waters issuing through this breach would have an effect similar to the sluice, till worn by the entering and issuing waters too wide to produce the effect, as was the case when Freestone's Sluice was worn too wide, it ceased to do its duty.

REFERENCES to the Plan of Wells Harbour.

Plate 1. Fig. 2.

	A.	R.	P.
1 Holkham Marsh, imbanked about the year 1719, by the late Lord Leicester, including creeks	560	0	0
2 Wells West Marsh, imbanked 1719, by Sir Charles Turner, including creeks	108	2	12
	668 2 12		
3 West Salt Marsh	588	2	0
4 Lodge Marsh	266	2	35
5 North, or Out Salt Marsh	717	2	25
Channels and creeks	146	1	12
	1,719 0 32		
6 East, or Church Marsh, exclusive of the ancient creeks	106	3	2
Creeks in ditto	4	0	0
	110 3 2		
7 Warham Slade, exclusive of the ancient channel and creeks	59	1	36
The channel and creeks in ditto	7	0	32
	66 2 28		
	Acres 2,565 0 34		

- A A The present entrance into the harbour.
 B The course of the Old Channel by the Scolph.
 C C The west side of the antient entrance into the harbour.
 D Friston's Jurties.
 E E The arrows shewing the set of tide over the sands on this coast, for the last three hours of flood and the first three hours of ebb.
 F The place of the second buoy at the turn by Broom's wreck.
 G The present navigable channel at the Scolph, since the imbankment made by Sir John Turner.
 H The present Pool.
 I The Quay.
 K The bank made by Sir John Turner in 1758.
 L The place to which the water used to flow before the imbankment made at K.
 M N The places where the waters from the west marshes empty themselves into the main channel
 P P The line from which it is supposed the water has drained towards Wells Harbour.

ABERDEEN HARBOUR.

The REPORT of JOHN SMEATON, Engineer, upon the Harbour of the City of Aberdeen.

(See a Plan, Fig. 1. Plate 2.)

THE principal complaint attending this harbour is the difficulty of entry, occasioned by a barr a little without the harbour's mouth, and a shifting bed of sand, gravel, and shingle on the north side of the entry, which, by the action of the seas, when the wind is in the north easterly quarter, drives into the main channel, choaking it up in different degrees, according to the violence of the sea, the state of the tides, and of the land speats, floods, or freshes in the river Dee, which here falls into the sea.

When I was there, which was in the month of August 1769, the entry was then said to be in a good state; and on sounding it upon the 7th of that month, which was the 6th day after the new moon, (and consequently the tides in a mean state between spring and neap), I found full four feet of water upon the bar at low water, and at high water the same day full fourteen feet; but it is said that the ordinary spring tides make but much about the same depth upon the bar at high water, and that at low water the barr is left with only the run of the river over it. The neap tides it is said usually make ten feet water upon the bar, but this is to be understood (I suppose) at such times as the entry is in a good state. On sounding at low water, I found the body of the bar to be composed of loose stones of different sizes, and the whole intermixed and compacted together with gravel, over which was a layer of sand from six inches to a foot in thickness, which after great land freshes is said to be quite swept away, and the stones and gravel left bare, which is its best state. The bar is but of short extent, and both within and without we quickly get more water by three feet. Without the bar the water gradually deepens and forms a very good road for ships to ride at low water, and is naturally protected from all winds except the north easterly and easterly, which blow right into the harbour's mouth, so that were there a little more depth of water over the bar, and this certain, this harbour would be capable of affording very good protection to merchant ships trading into these seas.

The

Plan of the HARBOUR of ABERDEEN as it was in 1769.



Plan of the HARBOUR with its Alterations, as proposed 1787 by J. Smeaton.



The cause of the obstruction of the harbour's mouth appears to me to be this : The whole coast, which stretches away northerly, is apparently for miles a flat and sandy shore, and I suppose from the harbour of Aberdeen till it meets with the point of Buchanefs, (which is at the distance of seven leagues), continues of the same kind ; consequently the wind at N. E. acting obliquely upon it, brings the sands and gravel intermixed coastwise towards the south ; and as the coast from the south side of the entry of this harbour stretches away nearly east for about three quarters of a mile, those sands would naturally be deposited in the angle of the coast formed at the harbour's mouth, did not the land waters of the river Dee, in finding a passage to sea, force themselves a vent, which they maintain more or less clear according as the circumstance of winds, tides, and freshes, balance one against another. A hard gale of wind at N. E. as already mentioned, gradually brings the sands and gravel coastwise southward, and puts in agitation that already lodged in the bank on the north side of the harbour's mouth, at the same time forcing it into the entry, and if at that time it happens to be spring tides and little fresh water in the river, a strong tide of flood being the consequence, greatly co-operates with the wind and seas in carrying a large quantity of sand and gravel into the channel of the river ; and the fresh water in the river being supposed then very short, the reflux will be very languid, and being counteracted by the impetus of the sea, it cannot return ; and a continuance of weather and circumstances of this kind, will put the mouth of the harbour into the worst state, in which it must necessarily remain till by a contrary disposition of circumstances a contrary effect is produced. On the other hand, a continuance of great land floods, either at spring or neap tides, accompanied either with off shore winds or moderate ones at N. E. gives the greatest advantage in scouring away the sands and gravel from about the harbour's mouth, carrying it out into the road, from whence by degrees it gets round the point of *Girdlenefs* ; and if towards the close of the work there happen along with a strong land fresh, low spring ebbs, which give the current the greatest fall to sea, and at the same time run bare over the bar with a moderate wind at N. E. which will give the sand some agitation without much impetus ; under these circumstances, the stony body of the bar will be cleared of sand, and the harbour's mouth be put in its best state, and so will remain till the contrary causes produce as before the contrary effects : and in this state of fluctuation must the entry of the harbour of Aberdeen ever remain, till something is done to counteract the effects of that arrangement of circumstances whose natural tendency is to do harm.

The only means by which I can see that this is likely to be effected, is the erection of a north pier, as shewn at N. N. in the plan, which will directly tend to the cure of the evil

evil complained of; for it will not only keep the land freshes more confined in a body till they come into deeper water, but what is of more consequence, will in a great measure prevent the sand and gravel from being driven in. It will not indeed stop the continual driving of the matter coastwise from the north, but after the back or outside of the pier is filled up with sand, &c. to a certain degree, it will then go round the pier head, and by the superior action of middling freshes and spring ebbs will be kept in deeper water, and so get round the point of Girdleness, without getting into the harbour's mouth, or at least not in such a degree as to obstruct the navigation. By this means, as the bar will not only be kept clean down to the stone bed, but by lifting the larger sort of stones by art, the remaining gravel will wash out into deeper water, so as to make (as may reasonably be expected) full two feet more water than there now is in its best state.

I can see no objection to the putting of this work into immediate execution, save the expense of it. To reduce this as much possible, I have endeavoured to propose such a construction, as, consistently with that solidity and permanency which a work of this kind ought to have, consists of the smallest quantity of materials and workmanship that I can think sufficient; and as the materials which nature furnishes here are of the best kind for the purpose, and are found near the place, I am in hopes that they will be raised and put together considerably cheaper than I have supposed in my estimate, which for that reason I desire may be considered in no other light than a form or blank, comprehending species and quantities: for as my stay at Aberdeen was necessarily short, the requisite examinations immediately relating to the harbour prevented my entering into those enquiries, which tended only to acquaint me with the price and value of labour and materials. I therefore can only fill up the blanks by comparison with what has been done at other places less advantageously situated with respect to materials, and perhaps that of labour also: in order therefore to come at a real estimate suited to the place, I must beg leave to refer myself to the enquiries of the magistrates concerning prices, or to a committee deputed by them for that purpose; and which, from their particular knowledge of the country and of the workmen, will I apprehend be done to more advantage than I could have done myself, without a longer stay than my other avocations could possibly admit of.

One thing, however, I must beg leave to suggest, that though what I now offer is as I apprehend the complete thing, which I expect to answer in the best manner, yet I am of opinion that it will be found if the pier be not carried out so far by 200 feet, that it will in a great measure relieve the present annoyances, nay, that it will be of singular service if carried out but just beyond the present pier, on the south side of the entry, in which case it will be shortened by 350 feet. In the former case the expense will be reduced according

according to my estimate by £2,028, and in the latter by £3,549; and as the work ought to be begun from Sandness Point, where it is easiest and cheapest to be done, the workmen will gradually learn the way of doing it to the best advantage, and will probably be able to contract for the more expensive part, upon better terms than would seem to them feasible at the beginning; and as the work advances, the benefit and effect will be seen, so that it needs not to be carried further than by experience shall be proved necessary.

I come now to the improvements that may be made in the internal part of the harbour. Here I cannot but lament that the course of the river is distracted by so many channels, and covers so great a breadth of ground at high water, which want of confinement is not only detrimental to the procuring of a deep channel at the harbour's mouth, but within the harbour also, and it is particularly disadvantageous that the main current of the river does not sweep the face of the town's key at L: this I should without any hesitation advise to be done by art, were it not for the fishing properties upon the main channel; but, as I must suppose them irrevocably established, it remains to point out what is the best that can now be done, the fishings remaining as they are. I observe that within the Point of Sandness there is nearly the same water as over the bar, till the main river channel and navigation channel divide, which part of the river is marked in the plan as the *Stell Fishing*. In this part of the river, which is land-locked from all winds, vessels that will bear the ground, and whose draft of water is such as not to admit of their going further up, may safely deliver their cargoes, or shelter themselves when they come in by way of refuge; but after the aforesaid division the navigation channel M M becomes immediately shallow, carrying however ten feet water till we arrive above the new pier called Pockraw Pier at K; when opposite the ropery and dock-yard it falls a little shallower to nine feet four inches, from thence it holds nine and a half and ten feet, till meeting with the town's pier or key E L, it again breaks into two channels viz. that which stretches along the face of the pier, and that which is called the Blacky Pool. The navigation channel by the pier side, from the aforesaid division, falls off at first to nine, then to eight, and gradually to seven feet water.

The desirable improvement pointed out to me, and which seems of great consequence to the trade of the city, is to deepen the navigation channel quite away from the new pier to the west end of the Town's Pier or Key.

I observed when there, that little or none of the current water of the river Dee, in its common state at low water, goes down either the channel by the face of the pier, or the Blacky Pool, all the outlets from the main stream that might be likely to take this course, being barricaded by stone dykes, raised from two to three feet, or thereabouts, above the ordinary

ordinary surface of the Dee's water, so that nothing worth notice, till the water is swelled above those dykes, can go down the above-mentioned channel, save the water of two small burns which empty themselves by the navigation channel. With these helps, however, but principally by the current that passes through it and the *Blackey Pool* during such speats as overflow the aforesaid dykes, the navigation channel is kept open.

It has been proposed to bank in the low grounds lying west of the old pier marked D, so as to pen in the spring tides, and at that place to erect a sluice to be drawn at low water, and by making an artificial scour to deepen the aforesaid navigation channel.

Great effects are capable of being produced by the operation and judicious management of sluices in situations adapted thereto: that is, where there is a great command of fresh water, or a considerable declivity in the part to be scoured. Here as the water to be pent in is not considerable in itself, must be in a great measure tide water, which, as the imbankation would in a great measure prevent all currency through it, would be subject to fill up the reservoir, and the length according to the navigation channel nearly a mile upon four feet only of descent at low water, I fear, these circumstances considered, the effect would not be found answerable to expectation. On the other hand, the imbankation preventing the speats which overflow the dykes from getting in at the head of the navigation channel, the principal natural agent would be prevented from operating, and which I should be sorry to lose. Were the long dyke, marked A A in the plan, broken down and removed, I make no doubt but that in the course of a few years the main stream of the river Dee would make its passage by way of the Denburn into the navigation channel, D E L M K, and by degrees of itself produce the effect desired, and with a little help would do it in a very few years. I state this not upon any supposition that the dyke is likely to be removed, but to shew more strongly the use of such natural advantages as still remain. I do not suppose, however, that any use that can be made of the remaining advantages will of themselves greatly deepen the navigation channel; but this I suppose, that after it is made deeper by art, those natural advantages may be so applied as to keep it equally clean at a greater depth, as they now do at a lesser.

The whole channel from the new pier at K to the town's pier extending from D to L, does not need a great deal to make it good ten feet water, and it may be very successfully deepened by a ballast lighter, constructed like those used upon the river Thames for getting ballast for the ships. Those lighters work by direction of the Trinity House upon such shoals as are most injurious to the navigation of that river, and all the ships of that port are obliged to take their ballast from them at a certain price. Perhaps much ballast

ballast is not taken out from the port of Aberdeen, but such as is, may be supplied by this lighter in aid, as far as it goes, of the expense of raising it.

The channel for the whole length of the pier or key I would propose to be deepened by the mattock and spade at low water, which deepening being done two feet at a mean, will give ten feet water to the middle of the pier where now there is but seven feet six inches; and this being done to a breadth of sixty feet will admit of two vessels to lie abreast with sufficient passage. This work will be attended with no extraordinary expense in proportion to the utility thereof, and will endure for several years before the state of the channel will return to what it now is; yet it would undoubtedly return by degrees to the same state, unless some counter-balance be applied to prevent it: what I would therefore recommend for this purpose is as follows:—

To erect a strong stone dyke beginning at the head of the Inch Dyke at F, in the direction of the dotted line F E to the beacon E upon the Trinity Inch; or if it should any ways happen to interfere with the Raik Fishing, to carry it from a lower part of the Inch Dyke to the said beacon, according to the direction of the dotted line G E: this dyke to be made so as to rise above and keep in the water of the high land floods at half ebb of the tide, and to be made firm, so that the current may in great land floods at high water go over it, without hurting it; by this means the greatest part of the water that in time of speats flows over the present dykes, and makes its way partly by the Blacky Pool, partly over the surface of the higher lands, and partly by the navigation channel along the face of the pier, will all be constrained to go through the channel alongside the pier, and therefore will be as adequate to keep clear that channel at ten feet depth, as the present channel joined to Blacky Pool is to keep it at that mean depth from their junction to the junction of the main river at the Stell Fishing: and as these operations are plain and simple, and will be attended with no considerable expense, I earnestly recommend their execution.

It is also very practicable in like manner to join the old pier D by a dyke across the Trinity Inch to the elbow of the river, a little above the Inch Dyke B; and also by putting sluices upon the opening between the north end of the old pier D and the west end of the town's pier or key to pin in the tides, in order to make artificial scours: but as the building and maintenance of sluices would be expensive, if made so capacious as not to be an impediment to the current and action of the land flood waters, as above mentioned, and would have no considerable effect, unless the water was pent up higher than the present fishing dykes, (the banks whereof if so would in a great measure prevent the flood waters going that way); it therefore appears that since sluices of any kind are likely

likely to prevent more good than they will do, that the plain, natural, and simple method first described, of making a dyke according to the single dotted line E F as first mentioned, is the most eligible to be put in execution. Upon the whole, I am of opinion the methods pointed out to be pursued, without and within, will remedy the complaints the harbour is subject to, as far as is above specified, and possibly in a still greater degree.

Aufhorpe,
19th February 1770.

J. SMEATON.

ESTIMATE for the North Pier of Aberdeen, &c.

This pier N N being begun at the high ground of a point called Sandnefs Point, marked X, not subject to be overflowed with the tide, may be carried out for 400 feet gradually increasing, being 20 feet base, 12 feet top, and 12 feet high, will contain as follows, videlicet,

£ s. d.

Cube feet of solid
rough blocks.

In the base for 2 feet high	-	-	-	40
In the side at 3 feet mean thickness and 10 high	-	-	-	60
In the platform at top	-	-	-	5

Solid rough blocks per foot running at 4d., £1. 15s; and for 400 } 105 700 0 0
feet length

To 87 cube feet of chiefly large and some small rough stones for filling, which reckoning 13 cube feet and a half to the ton (that is, 2 ton to the cube yard), makes 6 tons and a half per foot running, which at 2s. 6d. per ton laid in place amounts to 16s. 3d. per foot running, and for 400 feet to 325 0 0

The parapet being at a medium 4 feet 6 inches base, 3 feet top, and 4 feet high, will contain 15 cube feet per foot running, and reckoning as before 4d. per foot for block stone, 2s. 6d. per ton for walling and filling stones, 2d. per foot superficial over all, for work in facing, and 2s. 2d. per cube yard for mortar and extra work in walling the parapets, will come to 10s. per yard, cube measure, and therefore for 15 feet to 5s. 6d. per foot running, and for 400 feet to 110 0 0

The 1st stretch of 400 feet of the pier £ 1,135 0 0

The

The 2d stretch being carried out 400 feet farther, being a mean 28 feet base, 14 feet 6 inches at top, and 20 feet high, will contain as follows:

rough blocks.

In the base for 3 feet high	-	-	60
In the sides 17 feet high and mean thickness 3 feet and a half	-	-	119
In the platform at top	-	-	7

Solid rough blocks per foot running 186 at 4d., £3. 2s.
To 400 feet in length at £3. 2s. per foot running 1,240 0 0
To 117 tons of large rough stones for filling, at 2s. 6d. per ton, comes to 885 0 0
£2. 4s. 3d. per foot running, and for 400 feet to
The parapet will contain a cube yard per foot running, which for 400 feet at 10s. comes to 200 0 0

The 2d stretch of 400 feet of the pier £ 2,325 0 0

The 3d stretch of the pier being carried out 546 feet beyond the former, and being at a mean 36 feet base, 24 feet top, and 24 feet high, will contain as follows:

The base of blocks 4 feet high	-	-	114
The sides at a medium 4 feet and a half thick each	-	-	180
The platform at top	-	-	10

Rough blocks per foot running 334 at 4d., £5. 11s. 4d.
This for 546 feet in length comes to 3,039 8 0
To 28-5 tons of large rough stones for filling, at 2s. 6d. per ton, comes to 1,951 19 0
£3. 11s. 6d. per foot running, and for 546 feet to
The parapet will contain 2 cube yards per foot running at £1. per foot, and for 546 feet 546 0 0

The 3d stretch of the pier 546 feet £ 5,537 7 0

The pier head to be 60 feet diameter at base, 48 feet top, and 24 feet high, will contain as follows:

The base of blocks 4 feet high	-	-	11,316
The outside at 4 feet and a half mean thickness	-	-	16,920
The platform	-	-	707

Rough blocks in the pier head 28,943 at 4d. 482 7 8
To 1,940 tons of rough stones for filling at 2s. 6d. 242 10 0
To 54 feet of parapet (being the length that the head is supposed to add to the 3d stretch, making it in the whole 600 feet) at £1. per foot 54 0 0

The pier head making 54 feet running £ 778 17 8

ABSTRACT

ABSTRACT.

			£	s.	d.
The 1st stretch containing 400 feet running	-	-	1,135	0	0
The 2d ditto	-	400	2,325	0	0
The 3d ditto	-	546	5,537	7	0
The pier head	-	54	748	17	6
Whole length	1,400	Total of the pier	9,776	4	6
The taking up the bar so as to make two feet water more than at present when clear, with incidental charges, may be supposed	-	-	223	15	6
		Total for the pier	£10,000	0	0

Aufhorpe,
19th February 1770.

J. SMEATON.

ESTIMATE for the Interior Works proposed for the Harbour of Aberdeen.

			£	s.	d.
The construction of a stone dyke in the direction F E, specified in the report and plans, being supposed at a mean 12 feet base, 6 feet high, and made rounding at top, will take about 37½ tons of rough stones per foot running at 2s. 6d. per ton, and being in length about 1110 feet, will come to	-	-	499	10	0
To clearing the channel from the new pier K to the town's pier L D, in length about 30 chains or 2220 feet, and being supposed to be deepened at a medium one foot upon 60 feet wide, will contain 4933 cube yards, which I suppose may be done by hand at low water for 6d. per yard, will amount to	-	-	123	6	6
To deepening the channel by the side of the town's pier L D, at a medium two feet upon 60 feet wide, for 1700 feet in length, will contain 7555 cube yards, which at 6d. will come to	-	-	188	17	6
The interior works	-	-	£811	14	0

Aufhorpe,
19th February 1770.

J. SMEATON.

To the Magistrates of the City of Aberdeen.

The REPORT of JOHN SMEATON, Engineer, upon the *In-run* of the Seas into the Harbour of Aberdeen in easterly winds.

(See the Plan, Fig. 2. Plate 2.)

IN consequence of the memorial from the magistrates of Aberdeen, dated the 9th of April last, which I received in London from the hands of Mr. Profeffor Copland, and of your further request signified to me by Messrs. Carnegie and Black of Montrose, I took the opportunity of visiting your harbour, and made my observations upon the place, 1st, 2d, and 3d of October last, at which time the wind happening to be easterly (though not very fresh) afforded me an opportunity of particularly viewing and considering the mode of the action of the seas from this quarter, and had the pleasure to find that the deepening of the the entry into the harbour, and removal of the bar, that was the principal annoyance complained of when I viewed the harbour in the year 1769, has been effectually removed and cleansed, and so kept continually in that improved state by means of the north pier N N, which has been erected conformable to my report of the 19th February 1770. But though the main object has been answered, and the harbour and refort thereto very greatly improved, yet the very means by which this improvement has been effected have produced a cause of complaint of a very different kind, which at the time I apprehend to have been altogether unforeseen, and that is from the increase of depth and freedom of passage, the swell of the sea at high water meeting with nothing to controul it, makes its way through the clear passage between the two piers, and meeting nothing within the great natural bason or bay that forms the harbour to break or disperse the seas so brought in; according to the nature of waves when passing through a narrow into an expanded space, they turn round along the shore and spend their fury upon the nearest objects in the greater degree, and in proportion upon those more distant.

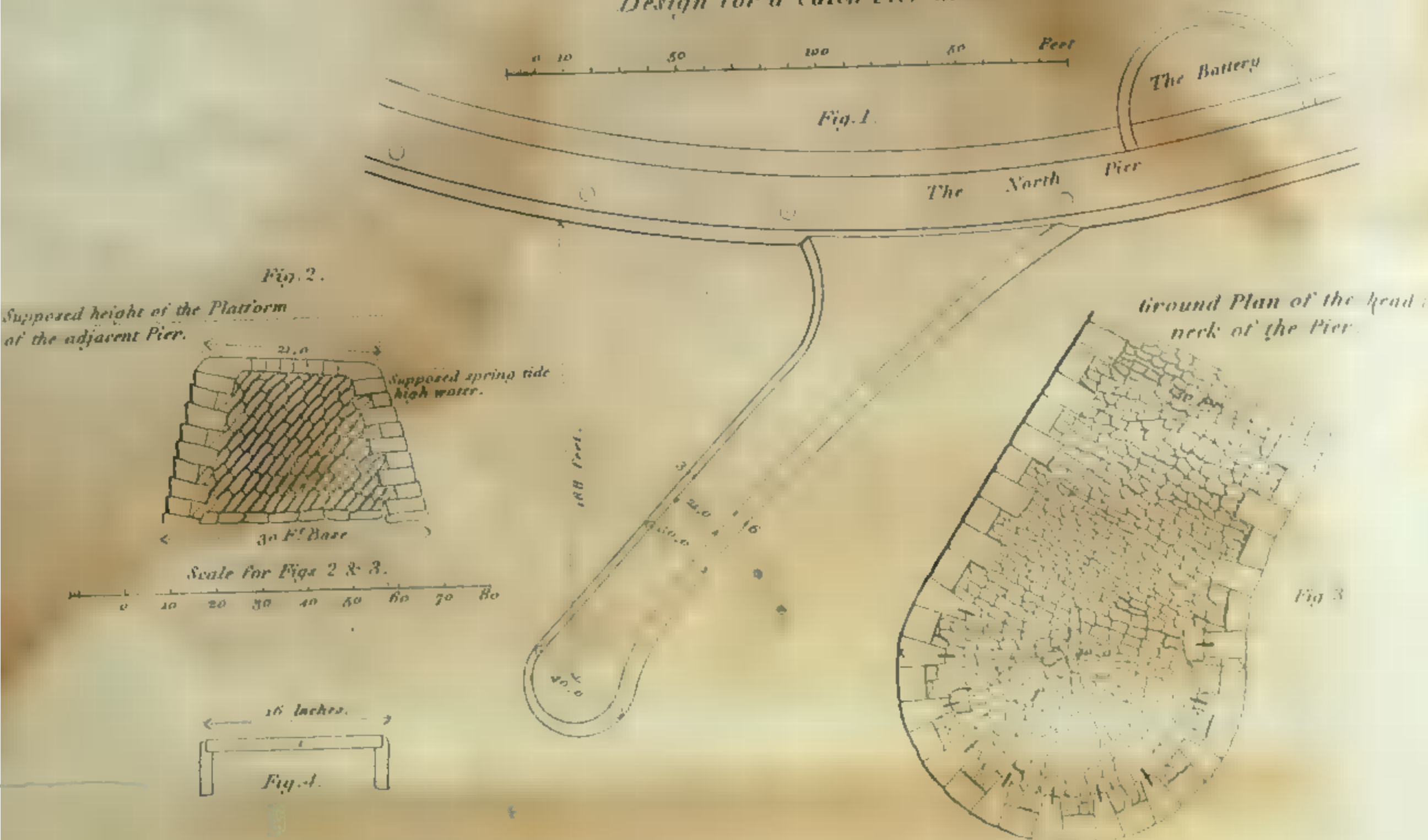
While the Old Sandness Point remained, which had been formed in former times before the north pier was built, and which extended more than half way across the space walled off by the new pier (as appears by the original Plan at X. Fig. 1.) this point of shoal water while it subsisted was capable of taking up and breaking the heavy seas in rolling over it, and thereby in a great degree dispersing them; but in proportion as the bar was removed and the entry deepened, the seas falling more heavy upon this point, have gradually dispersed and removed it, and in consequence now pass into the harbour without controul, as has been fully and clearly set forth in your memorial above referred to.

The

The cause of the present in-run in consequence of these alterations, being clearly owing in a great measure to the loss of the Sandness Point, it further appears that, if restored, it would be inadequate to the dispersion of the seas that now enter, owing to a greater depth at the mouth. The remedy therefore is clearly pointed out to be a construction that shall not only have the effect that it had in its original state, but one so much greater as may be in proportion to the greater weight of the seas, which from the causes stated are now liable to fall upon it.

The cause and the mode of cure being both perfectly clear, there can be no difficulty in judging that something should be done at the Sandness Point in order to its restoration; but in what particular mode and degree, as also that it may be done in the most economical as well as effectual way, have been to me matters of much reflection and study.

The first thing that presents itself is, to begin from the side of the pier near about where the Old Sandness Point was, and to deposit a body of rough stones projecting gradually forwards towards the middle of the open space, rising towards the pier and sloping towards the low water; and as this work will naturally be done in progression, it may be gradually carried on till it is found to produce the desired effect; and this is doubtless the clearest and easiest way of doing the business, and no more needs to be done than what is sufficient; so that in effect the *New Sandness Point* will now, instead of sand and gravel, be composed of a body of rough granite. This mode in its commencement would appear to be the most economical, but it is very probable that before it is ended it will require so great an area to be covered, as to contain so considerable a quantity of stone, that the same tonnage of stone being put into a regular shape would form a regular catch pier. The stones composing such a mound or bulwark must not in general be of a small size, because if the seas breaking upon them remove them and wash them into the navigable channel, they will produce an obstruction of a third kind; and if formed of large stones, I apprehend that as the quarrying and carriage of such stones will so far exceed the cost of putting them in shape when brought to the place, that they may just as well be made to form a regular piece of work. I have, however, no doubt but that the mound now proposed would fully answer the end; and if the magistrates are inclined to adopt the mode of construction, the outline of it, describing the spread that I apprehend it may be needed to have when completed, is very well described by the chain of dots that I left upon the plan that had been presented to me along with the said memorial, (these are seen in Fig. 2. at a a). In regard to any further directions they seem unnecessary, as the work is to prove itself, the sea being to break over it,
it



it is only necessary to keep it constantly higher towards the pier, and sloping towards its base on all sides, as has been already mentioned, and was the case of the natural point.

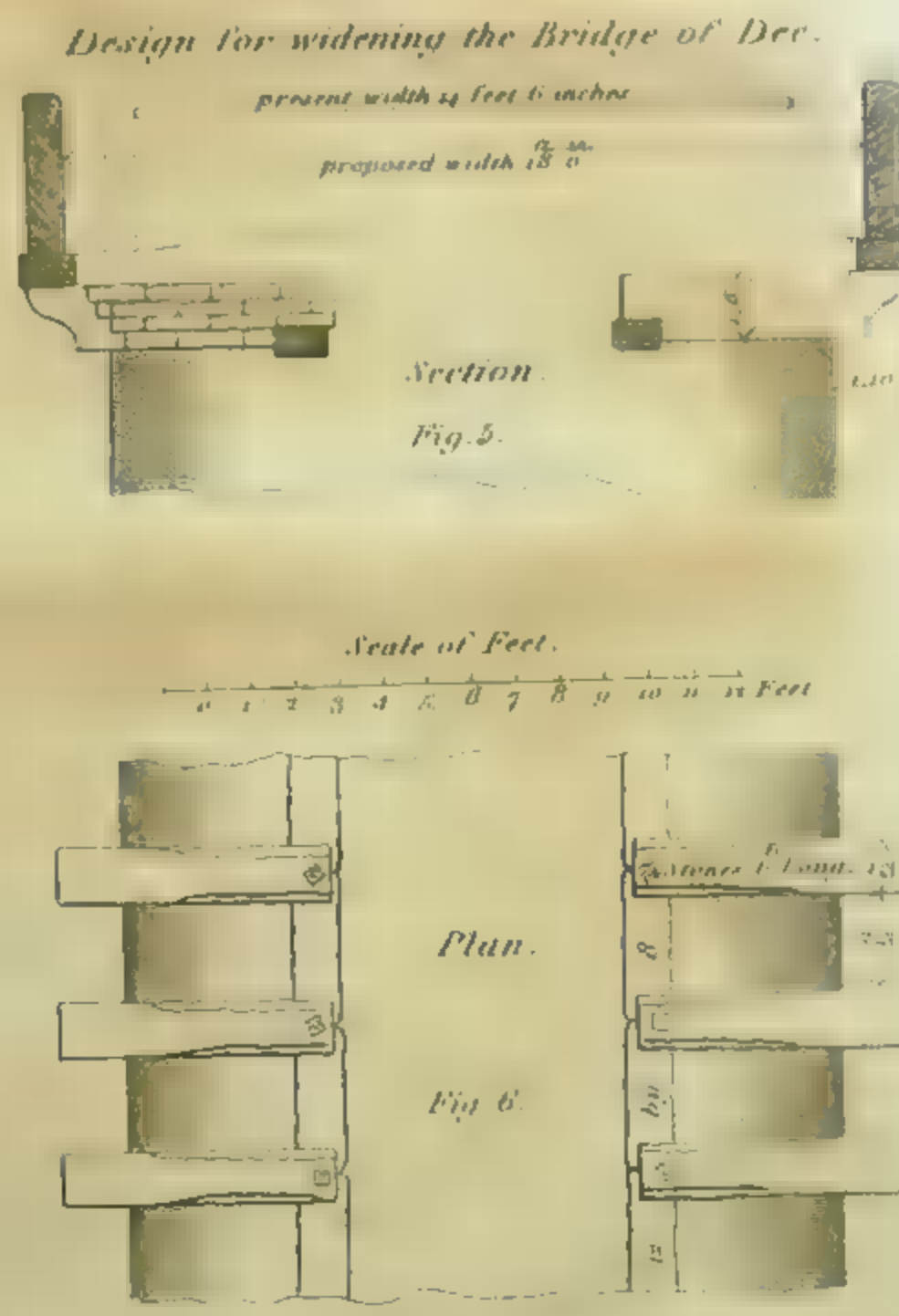
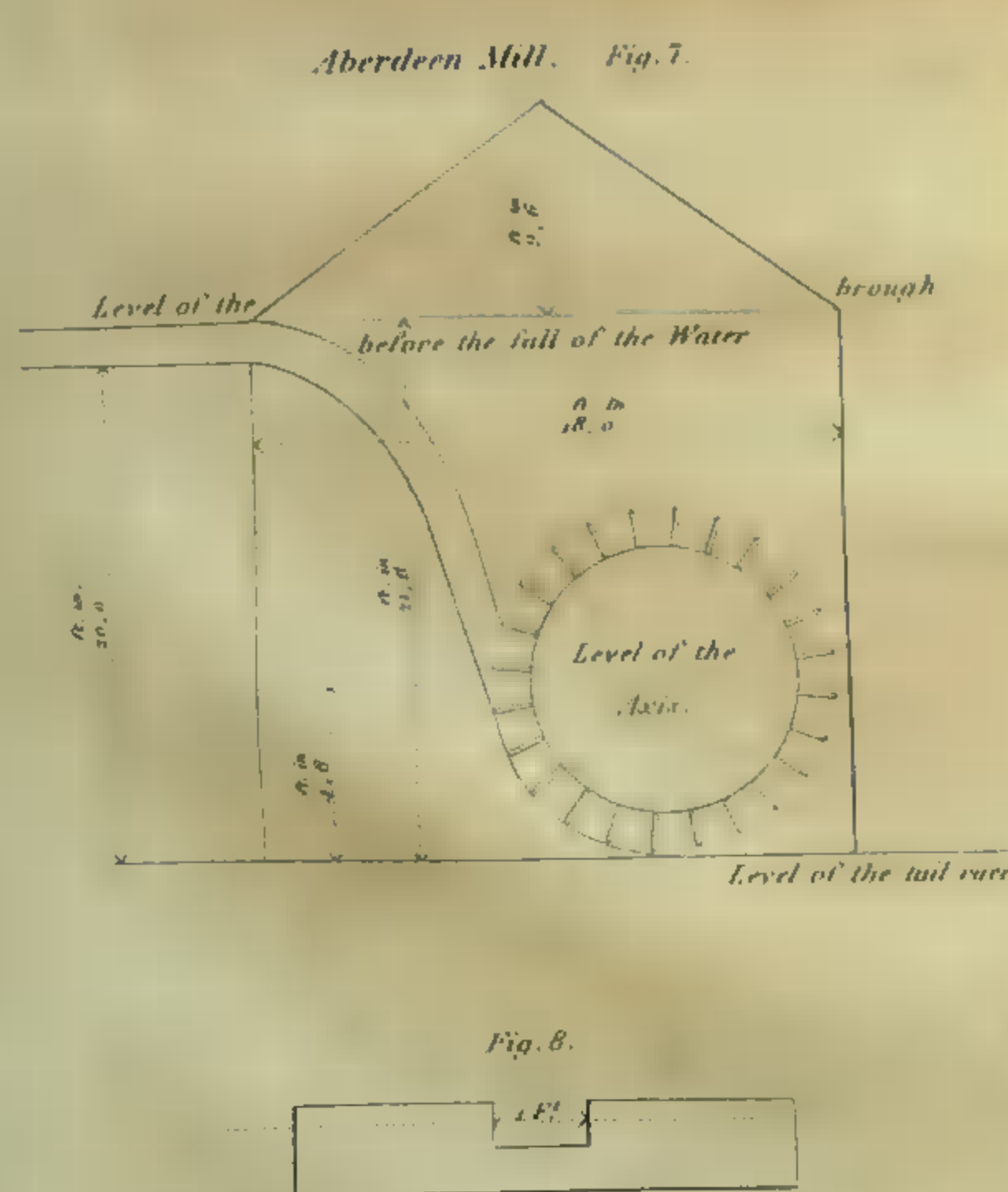
I herewith send a general Plan, (Plate 3.) shewing the shape, situation, magnitude, and projection of a catch pier in respect to the present works, and which if carried out to the extent described, I have no doubt will have the effect of quieting the harbour; and as it will leave a clear breadth of full 300 feet for the navigable channel, I apprehend there can be no objection to its projecting the full extent of 180 feet from the side of the present north pier, if so required; but as it is not improbable, and indeed what I rather expect, that half of this projection may be found sufficient, when other things are done that I pointed out when upon the place, and shall further enlarge upon, I would first propose to carry it out to the length of 90 feet, building up the head with a square return, in the manner that was done on quitting the work of the north pier at the conclusion of each season; and this being done, the effect of one winter will shew what more will be necessary, and in consequence the head as designed may be immediately joined upon it, or it may be carried out to the full length, or to such extent as may then be judged requisite.

As this catch pier, so far as I can see, is not likely to be of use except as a break water, I do not mean to build it so high as the other, but to about spring tide mark; the seas being suffered to break over it at high water, which will in fact have more effect towards their total dispersion, than that of solely diverting their course; for till they are broken and destroyed they will always recoil and produce the effect somewhere.

As I find by experience that there is nothing that so much tends to quash and disperse a wave when it is raised, as its breaking upon a sloping beach; on this account the continuance of the south pier Z Z (Plate 2. Fig. 2.) so far to the westward, (which seems to have no other effect than as a wall to wharf up the sloping shore that lies opposite to Sandness Point), has in reality a very bad effect in the present state of things, in keeping the seas from spending and breaking as they would otherwise be inclined to do upon the naturally sloped shore at that place, as the flooded pools lying here behind the pier do testify. For what reason this wharfing has been carried so far west, it is not now easy for me to conjecture; but doubtless the ill effect of it would not so clearly appear before the erection of the north pier, as the north side was then a sloping beach entirely. But for whatever reason it was done, the removal of it now is altogether necessary, for the shape and tendency of the catch pier now proposed, being to throw the seas more effectually over to the south side, unless there is a sloping beach for them to break upon, they will be

VOL. III.

H



be again reflected back from that side towards the north, and undoubtedly produce disagreeable effects in some part of the harbour. I therefore propose, from the place specified in the plan, where the west end of the south pier is proposed to be terminated, to remove the present wall entirely, making it a sloping beach quite away to Torry Pier; and to mend the slope artificially where wanted: the stones will go in aid of the work to be carried on upon the north side. Fig. 1. of Plate 3. is an enlarged plan of the catch pier as now proposed, accompanied with a section, Fig. 2. and a plan, Fig. 3. of the ground course of the pier head, the two last to a still larger scale, and which, with the following explanation thereon, I apprehend will be sufficient for the guidance of the artificers.

There is not proposed to be any work upon the stones of the outside, further than splitting at the quarries; and as in the splitting of granite they can as easily be cut into wedge-like pieces, as made of parallel shapes, I have shewn a method by which the stones composing the circular end of the pier can be retained in their places, as effectually or even more so, than where the pier goes out near upon a straight line: for by making every other stone a long stone or header and more wedge-wise than the tendency towards the centre, the stones lying betwixt them may be retained in the manner of a dove-tail, and the header stones themselves being anchored at their tails, that is at their inward or smaller ends, to an anchor or cross stone by means of an iron cramp to each, the whole will be held compactly together. These wedge stones may be of different sizes, as they will cut to the most advantage in the quarry, as well as the intermediate stones; all that is required, is, that they decently fit each other.

The wedge-like header stones, employed to make the turn of the head, and hold in the intermediate stones between them, are to be tied to the anchor stones (see Fig. 4.) at their tails by iron cramps of one inch square, turned down and rounded at each end to go into jumper holes, to be fixed therein if necessary, with wood wedges without lead, as the weight of the courses above them, bonded in the same way, will be sufficient to keep them from starting.

I have fully attended to the contents of Mr. Carnegie's letter of the 24th ult. which only shew that something effectual must be done, even to preserve the internal works of the harbour; but when what is proposed is put in complete execution, I expect the tongue, and all its complaints, will vanish of course by degrees.

Author,
22d March 1788.

J. SMEATON.

ABERDEEN BRIDGE AND MILLS.

(See Plate 3. Fig. 5. and 6.)

The REPORT of JOHN SMEATON, Engineer, concerning the Improvement of the Bridge of Dee, near the City of Aberdeen, and of the Common Milns of the said City.

THE Bridge of Dee appears to be well built and of very good materials, and the current of the river seems to set fairly through the arches, so that it promises a duration for many years. Like most bridges formerly built, it is too narrow, being but $14\frac{1}{2}$ feet wide within the parapets, which is too little for carriages to pass with that ease, freedom and safety which are desirable. It is found by experience that 18 feet clear width admits of this convenience, and as this may be procured without deranging any of the more solid parts of the bridge, it seems a desirable improvement.

As the country affords an abundance of excellent granite, which, with little work upon it, is capable of being split into square blocks or pillars, I propose to widen the bridge by laying out corbells of granite of one foot ten inches projection, and removing the parapets one foot nine inches further out on each side on the corbells; the bridge will then be full 18 feet in the clear. The particular method of construction will be better understood by the design than by many words. Upon which I have only to observe, that to prevent the least apprehension of the weight of the parapets oversetting the interior weight, I propose that the spaces between the corbell stones be walled solid, and upon the ribband stones which connect the tails of the corbells; so that of masonry and earth there will be more than double the counterpoise. The corbells are each to have a bolt to hold them down firm upon the ribband stones; these are seen in the plan, Fig. 6; they must have T heads in order more effectually to engage the ribband stones; four inches in the T will be sufficient.

Having carefully considered the situation of the Town's Mills, I am of opinion that of the two mills within the city, now appropriated to the grinding of malt, if the machinery were made new, one of the mills may be made to do the business that is now done by both. This being the case, there will be one of the mills within the city that may be applied

plied to the grinding of corn, that is, to the shelling of oats and grinding of oats and barley. I apprehend the malt mill may be altered for about £80. and the other to a corn mill for about £150.

On considering the situation of the Justice Mill, I apprehend it will be best to be fitted up for the purpose of a wheat mill, for which it has been designed. I judge, that when the full advantage of the situation is taken, and the machinery properly adapted, the mill may be made to grind and dress full four Winchester bushels of wheat per hour, which, when there is water in winter and wet seasons, may be continued for the whole 24 hours, and in dry seasons such as it was when I was there, about 12 hours in 24; so that in the short water seasons, it will be able to grind and dress at the rate of 12 bowls (supposing four Winchester bushels each) per day. The expense of erecting such a mill originally would be about £500; but as I expect the mill-stones will do again, with the small machinery, these, with the larger materials and the buildings, will probably stand instead of £200. so that to rebuild the mill and make it fit for business, will require a further outlay of £300. As I had not a sufficiency of time upon the place to take the necessary measures, I can only guess at the quantity of business to be done, and the expense that may attend each of the mills; but in case the above idea appears eligible to be pursued, by receiving answers on the following points, I shall be enabled more exactly to calculate what they will do, and form a proper design for their rebuilding.

1st. A plan and elevation of each of the mill buildings as they now stand.

2d. The whole perpendicular fall of the water from the level trough, lander, or chute, before it begins to fall towards the wheel to the bottom of the race at the tail of the wheel, noting upon the elevation where the horizontal lines cut the elevations of the respective buildings, the sketch in Fig. 7. Plate 3. which is merely ideal, will be sufficient to show better than many words, what I want to have ascertained.

3d. Whether the water cannot without difficulty be brought to the place of its fall upon a still higher level, and whether the tail of the mill cannot be sunk deeper, so as to increase the fall, an advantage in either of these particulars of half a foot is worth noticing. Upon this head I must observe, I expect the lower mill within the town may have its tail race considerably lowered; for that reason I should be glad to know how much its bottom is above the ordinary high water mark, not only of spring tides, but of the neap tides also. In respect to the Justice Mill, my proposition is to conduct the water to it, not from the tail of the upper mill, but upon the level of the head of the upper mill, as far as the height of the adjacent ground will admit, and then to take it into lander troughs to convey it over the declining ground into the wheat mill: and that there may be

be no level unnecessarily lost in conducting the water, I should be glad to know the whole fall from the lead, after it has passed the road next the mill-pond, to the tail of the present wheel, and from thence as far as the town's lands stand, or they have power to let it fall, noting the respective distances, as also how far the water can be conducted on the surface of the ground in the lead from the mill-pond to the mill, and how far it will be required to be carried in a trough. According to this proposition, the upper mill may be left standing as it now is, to perform the service it is obliged to do: but the water will then pass by the wheat mill, without turning it, if this service will too greatly encroach upon the wheat mill, it will be the most compleat way of all to fix up the mill stones of the upper mill, to be turned by the wheat mill wheel, as then the upper mill service will be dispatched in one-fourth of the time; but then this will occasion some addition of expense in new constructing the wheat mill; yet the wheat mill may be so constructed as to admit of this addition afterwards, in case it shall be found necessary.

4thly and lastly. An experiment should be tried upon each stream of water in the following manner:—Let a board of three, four, or five feet long have a notch cut in it as in Fig. 8. of one foot wide, and about six inches deep, which fix in any convenient part of each of the watercourses either above or below the mills, but so that no water may go through it but what is employed in turning the mill referred to; this board is to be fixed in the manner of a dam, and to be made up with earth, clay, turf, fods or seal, so that all the water turning the mill may be constrained to go through this notch, and not to be interrupted by any water below it. The mill, in case it is not a time of short water, is to have its water passing the notch shortened, till it is as near as possible, in the judgment of the miller, the same quantity as they let down to work with in short water times; and the miller is to specify how many hours in 24 they can generally grind per day in dry seasons at that rate. While the water is thus going through the notch, it is to be noted, how much the dead surface of the water lying against the board on the upstream side of it is below the top of the board, and to be measured at the distance of at least six inches on one side the notch; this being done on each side of the notch at the same distance therefrom, and if any difference taking the mean, this subtracted from the whole depth of the notch, gives the thickness of the water flowing through it:—From this experiment I shall be enabled to calculate exactly how much business can be dispatched by each mill.

Upon the whole, as streams of water run scarce in the neighbourhood of Aberdeen, it seems of consequence to make the best use of those so advantageously situated.

Auslhorpe,
19th February 1770.

J. SMEATON.

plied to the grinding of corn, that is, to the shelling of oats and grinding of oats and barley. I apprehend the malt mill may be altered for about £80. and the other to a corn mill for about £150.

On considering the situation of the Justice Mill, I apprehend it will be best to be fitted up for the purpose of a wheat mill, for which it has been designed. I judge, that when the full advantage of the situation is taken, and the machinery properly adapted, the mill may be made to grind and dress full four Winchester bushels of wheat per hour, which, when there is water in winter and wet seasons, may be continued for the whole 24 hours, and in dry seasons such as it was when I was there, about 12 hours in 24; so that in the short water seasons, it will be able to grind and dress at the rate of 12 bowls (supposing four Winchester bushels each) per day. The expense of erecting such a mill originally would be about £500; but as I expect the mill-stones will do again, with the small machinery, these, with the larger materials and the buildings, will probably stand instead of £200. so that to rebuild the mill and make it fit for business, will require a further outlay of £300. As I had not a sufficiency of time upon the place to take the necessary measures, I can only guess at the quantity of business to be done, and the expense that may attend each of the mills; but in case the above idea appears eligible to be pursued, by receiving answers on the following points, I shall be enabled more exactly to calculate what they will do, and form a proper design for their rebuilding.

1st. A plan and elevation of each of the mill buildings as they now stand.

2d. The whole perpendicular fall of the water from the level trough, lander, or chute, before it begins to fall towards the wheel to the bottom of the race at the tail of the wheel, noting upon the elevation where the horizontal lines cut the elevations of the respective buildings, the sketch in Fig. 7. Plate 3. which is merely ideal, will be sufficient to show better than many words, what I want to have ascertained.

3d. Whether the water cannot without difficulty be brought to the place of its fall upon a still higher level, and whether the tail of the mill cannot be sunk deeper, so as to increase the fall, an advantage in either of these particulars of half a foot is worth noticing. Upon this head I must observe, I expect the lower mill within the town may have its tail race considerably lowered; for that reason I should be glad to know how much its bottom is above the ordinary high water mark, not only of spring tides, but of the neap tides also. In respect to the Justice Mill, my proposition is to conduct the water to it, not from the tail of the upper mill, but upon the level of the head of the upper mill, as far as the height of the adjacent ground will admit, and then to take it into lander troughs to convey it over the declining ground into the wheat mill: and that there may be

be no level unnecessarily lost in conducting the water, I should be glad to know the whole fall from the lead, after it has passed the road next the mill-pond, to the tail of the present wheel, and from thence as far as the town's lands stand, or they have power to let it fall, noting the respective distances, as also how far the water can be conducted on the surface of the ground in the lead from the mill-pond to the mill, and how far it will be required to be carried in a trough. According to this proposition, the upper mill may be left standing as it now is, to perform the service it is obliged to do: but as the water will then pass by the wheat mill, without turning it, if this service will too greatly encroach upon the wheat mill, it will be the most complete way of all to fix up the mill stones of the upper mill, to be turned by the wheat mill wheel, as then the upper mill service will be dispatched in one-fourth of the time; but then this will occasion some addition of expense in new constructing the wheat mill; yet the wheat mill may be so constructed as to admit of this addition afterwards, in case it shall be found necessary.

4thly and lastly. An experiment should be tried upon each stream of water in the following manner:—Let a board of three, four, or five feet long have a notch cut in it as in Fig. 8. of one foot wide, and about six inches deep, which fix in any convenient part of each of the watercourses either above or below the mills, but so that no water may go through it but what is employed in turning the mill referred to; this board is to be fixed in the manner of a dam, and to be made up with earth, clay, turf, fods or seal, so that all the water turning the mill may be constrained to go through this notch, and not to be interrupted by any water below it. The mill, in case it is not a time of short water, is to have its water passing the notch shortened, till it is as near as possible, in the judgment of the miller, the same quantity as they let down to work with in short water times; and the miller is to specify how many hours in 24 they can generally grind per day in dry seasons at that rate. While the water is thus going through the notch, it is to be noted, how much the dead surface of the water lying against the board on the upstream side of it is below the top of the board, and to be measured at the distance of at least six inches on one side the notch; this being done on each side of the notch at the same distance therefrom, and if any difference taking the mean, this subtracted from the whole depth of the notch, gives the thickness of the water flowing through it:—From this experiment I shall be enabled to calculate exactly how much business can be dispatched by each mill.

Upon the whole, as streams of water run scarce in the neighbourhood of Aberdeen, it seems of consequence to make the best use of those so advantageously situated.

Aulshorpe,
19th February 1770.

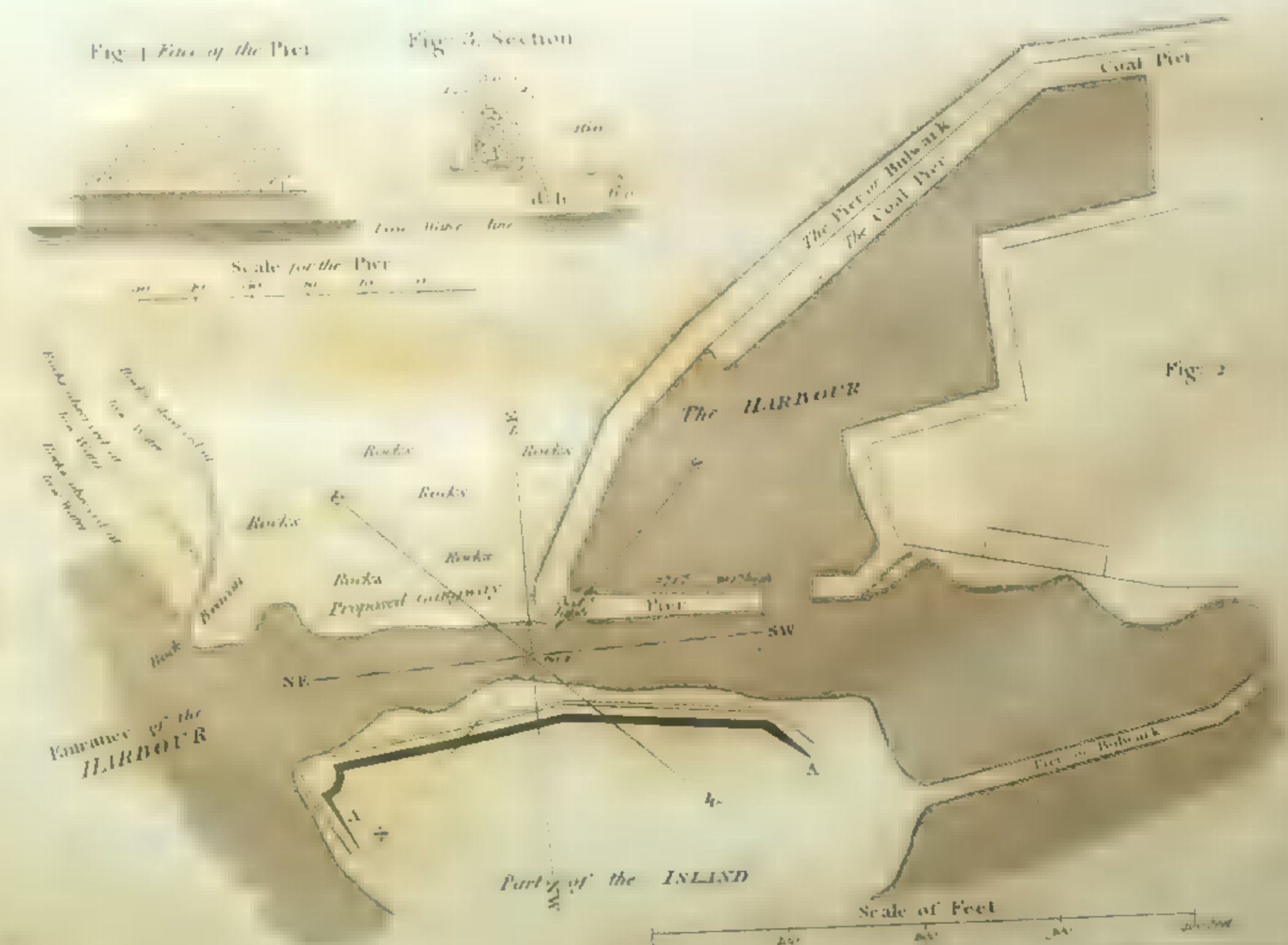
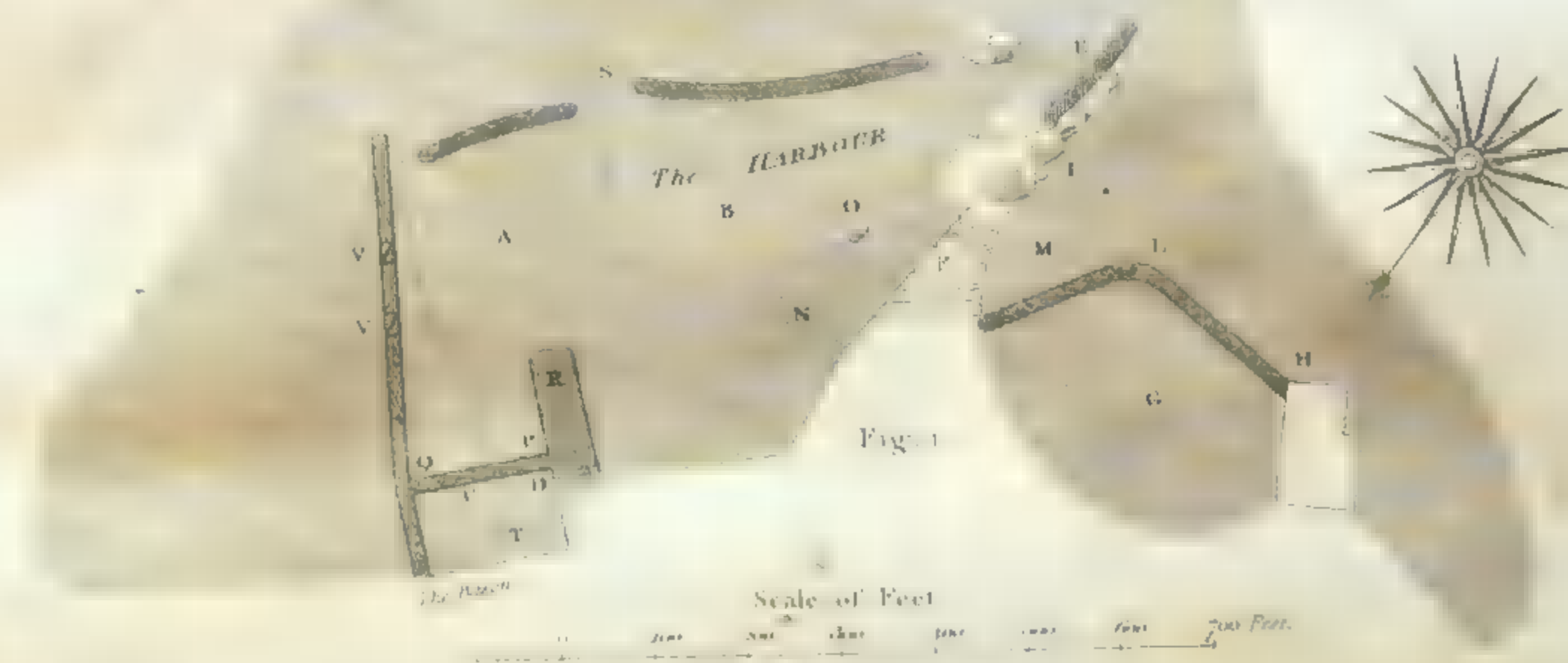
J. SMEATON.

DUNDEE HARBOUR.

(See the Plan, Plate 4. Fig. 1.)

The REPORT of JOHN SMEATON, Engineer, upon the Harbour of Dundee.

IT is a very difficult thing to make an artificial harbour to be in all respects complete, for the very means that tend to render it safe and quiet for vessels, tend to make it less easy of access, and more subject to mud, silt, or sand, such as the coast happens to be annoyed with. The harbour of Dundee by being too much inclosed is too subject to mud, and in such a degree as greatly to diminish the space inclosed, especially for larger vessels. I observe that the places where the mud chiefly lies are at A. and B. which are several feet higher than the entries and spaces near the runs of the sluices, particularly that at B. The present means of clearing it are by drawing a complete quantity of water from one or other of the sluices upon the basin at C. or D. and by a number of men set to confine the current into a channel at pleasure, and throwing in the mud, whereby it is carried without the entries, and thence taken away by the run of the tides. This operation it is said answers pretty well as to clearing the harbour, but it is attended with considerable expense, and requires to be too often repeated. Notwithstanding what assistance can be given by running the sluices, when unassisted by men at the bottom, it is said that before the pier E. was projected so far, and before the Ground was made up at F. between the little bay G. and the harbour, that it was then less subject to mud, particularly at B. and indeed this very well corresponds with the reason of the thing, for I observed when there, the 4th August 1769, being the third day after new moon, and consequently at the height of spring tides, that on tide of ebb a very strong current set past the end of the pier E. and was diverted thereby from the harbour's mouth; of consequence were there proper openings made in the neck at F. though they cannot be expected to clear away the mud at B. already deposited, yet being once done by other ways, this will be the most likely means of keeping it clear; I would therefore recommend that this neck be pierced by two sets of tunnels, in the directions shewn at F. three and three together of 12 feet wide each. They may be arched over so as to make good the platform at top, or by way of saving arching, may be shortened according to the dotted line at F. Those tunnels should be made with a clear passage



passage as low as they can be made for the rocks, or to low water mark. The cross wall H I. instead of being carried from H. to I. must be turned round at L. so as to leave open the space M. of its natural depth. That the tunnels may be freely supplied, the present little pier shewn by dotted lines at N. should be totally removed, and the rock at O. should be levelled with the rest surrounding it, and the whole so reduced as to give all freedom of water-way possible through the tunnels, and in this state of things, if the pier E. had occasion to be carried out still further, it would bring the tide more forcibly through the tunnels.

The means above-mentioned, by promoting a more free circulation of water through the harbour, would tend to keep down the bank of mud at A.; but I cannot think it would effectually keep it clear; but I apprehend when this is once done by the help of men, as before, by a more judicious disposition and application of sluices upon the present bason, the whole harbour may be kept in a great measure free. In the first place, I apprehend the water-ways of the sluices are much too small, for though the bason itself is much smaller than were to be wished, yet the letting the water go off in a small body though continued a longer time is not making the best use of it: a certain power of water will move that very expeditiously, which applied in a less degree will let the subject remain at rest. Consequently, the water being discharged from the bason in a large body, will do that in five minutes, which would remain undone, if the capacity of the opening were reduced so as to play a quarter of an hour; for this reason I would advise the sluices to be full three feet square in the orifice, and to be laid rather lower than the bottom of the bason. The sluice D. may still remain the place for one of them, but instead of the sluice C. I would advise two upon that line at P. and Q. of the dimensions afore said: That at P. will more directly tend to scour the face of the pier R. than in its present position C. and also to keep down the growth of the mud at A. and more especially if a passage be first opened for it, to vent its water by the opening S.; but the sluice P. being so much nearer the pier R. it will be so much farther from the east pier; to keep the face whereof clear, it will be proper to have the other sluice mentioned at Q. which will also serve a secondary use; for as the bason itself is liable to fill with mud, which I suppose it is a considerable expense to remove, this may be prevented by building a cross wall according to the dotted lines, with a sluice upon it at T. of equal size or rather larger than the others, constructed so as to pen the water either way; this sluice may therefore be made use of by penning the water in one half of the bason to scour the other, and so alternately; and when open suffers the whole bason to act by any of the interior sluices; to avoid loss of water, it will be proper to have all the sluices, particularly those at Q. P. and D. executed in the most substantial manner. I cannot

cannot advise the doors to be cut, in order to make a valve to let the water in, but rather to set one of them open by hand ; and to prevent accidents by neglect, a small tunnel with a valve in part to let in and effectually to keep in the water, may be fixed in the present opening at C. This I think will be the most effectual way of applying the water of the basin without the use of men, and I think it would also add, if to the opening in the east pier, which if I remember right is there already, there were another added, not less than 25 feet wide, so that they may be nearly in the position V V. By these means, I expect the harbour may, when once cleared, be kept clear, or so nearly so, that with a little help from men occasionally, to direct the water to particular places, it may be effected in the most easy manner that the situation will admit of.

J. SMEATON.

N. B. To prevent loss of room in the basin by the cross wall, it may be a strong stone wall, well built with lime, and assised on the two outides.

DUNBAR HARBOUR.

(See the Plan, Plate 4. Fig. 2.)

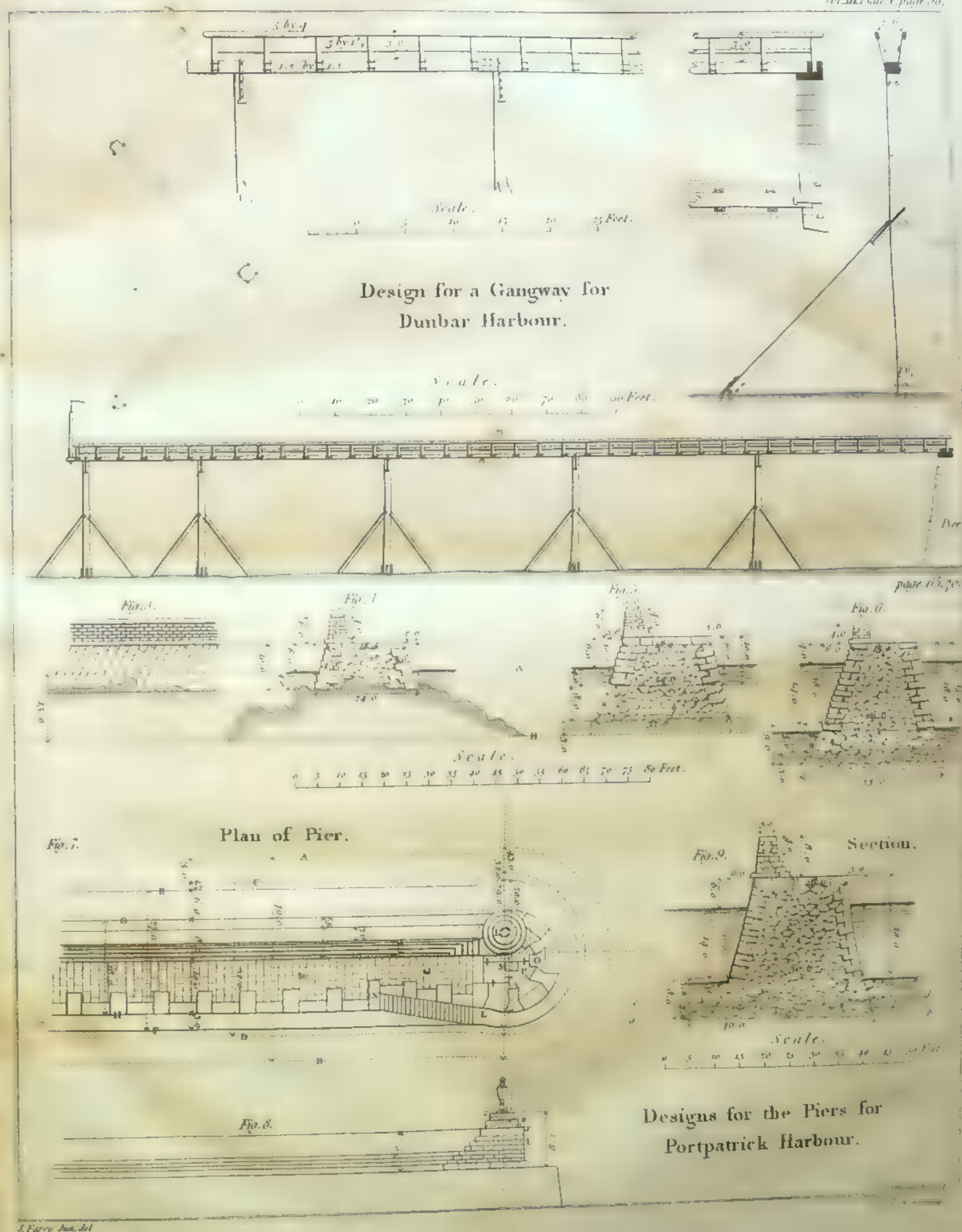
The REPORT of JOHN SMEATON, Engineer, upon the Harbour of Dunbar.

THE harbour of Dunbar appears from its form to be well adapted for the security of vessels lying therein, and as it is situated in the bottom of a bay, exclusive of the trade that is usually carried on there, it becomes of consequence to the security of vessels trading on this coast ; and its principal deficiency in both these views is the want of a good access, particularly in going into it ; and this is not owing to an improper course or direction of the entry from the bay, but from the narrowness of the passage, which is rendered in effect still narrower from the sloping form of the rocks on the starboard or N. W. side going in, to avoid which, vessels are obliged in prudence to keep nearer to the pier than they otherwise would do, and by this means, by the recoil of the sea from the rocks, are often driven against the pier, or upon the sloping rocks that are sunken and hid. To remedy this inconvenience as much as possible, it has been very properly proposed to cut off a certain part of the slope of the rocks, down even with the bottom of the rest of the passage, and to build the face up above high water mark, (as shewn at A A. in the plan), by which means, as the passage will not only be actually widened full five yards in the narrowest place, but by giving opportunity to vessels to see every thing that can hurt them, they may safely keep several yards further from the pier than they could otherwise have done ; the passage thereby in the narrowest part being rendered from about 45 to 60 feet wide ; at the same time the sea being prevented from breaking upon the sloping rocks, it will recoil with less force than at present, and the vessels will be less subject to be carried from side to side for want of sufficient way through the water. Lastly, this new pier or facing to the side of the entry being carried up sufficiently above high water mark, it will enable assistance to be given by throwing a rope on board from the most projecting point thereof, so as to tow in vessels when they do not come in with sufficient fresh way, to keep them clear of either side of the entry.

With the same view it would be well if a pier could also be carried out upon a ledge of rocks (which are dry at low water) on the S. E. side of the entry from the north angle

of the present pier, to the Beacon Rock. This would not only defend the passage from the furge of the sea, but by its projection also enable assistance to be given by throwing a rope on board on the larboard side of the ship, of which there is always an equal chance of its being preferable, by its being nearest; and still more effectual when it can be done on both sides. To this however may reasonably be objected the great expense that must necessarily attend the execution of a pier of sufficient bulk and strength to stand in this place the full stroke of the sea: however, to take advantage of that part of the utility of a S. E. pier, which consists in giving assistance by a rope, I have contrived a gang-way to extend itself in the same direction as far as the Beacon Rock, as shewn by the dotted lines in the plan, whereby any competent number of men will be able to give the same assistance by heaving a rope on board, as could be done on a stone pier, and which is contrived on principles so simple that it may be executed at a very moderate expense. This will be sufficiently explained by a design on purpose, (see Plate 5.) shewing how the same is to be executed, and indeed, had I not a good deal of experience in the use of fixing temporary utensils in the building of the Eddystone Lighthouse, I should have been very dubious in proposing a structure seemingly so slight to stand the violence of the sea. But there I learnt, that where the force of the sea is to be rather eluded than resisted, the less matter is opposed to its action the better, provided that this be but fixed in the firmest manner. I believe the whole of the design will occur from the plan, save the manner of fixing the iron bolts into the rocks, which are not proposed to be done with lead, as that is perpetually working loose, but in the following manner:—Round holes about 18 inches into the rock more or less, according to the firmness thereof, are to be bored with a jumper of $1\frac{1}{4}$ inch diameter; to these the eye-bolts are to be forged a very small matter taper, and larger so as to drive tight to their proper depth, with an iron maul; if they happen to be a small matter too small, then strips of plate iron put in along with them will make them to drive firm, and the rust will fix them from drawing.

Respecting the proposed pier or wharf (A A in the plan), as it will receive the full stroke of the sea, with a S. easterly wind, it will be necessary to be built very firm, and I believe it will not fully answer the end if the ordinary seas break over it; I therefore propose it to be raised nine feet above high water at spring tides, that is 22 feet above the low water line at the pier head, but it may decline in height as it runs S. westwards towards the land. This height will carry it considerably above the rocks where it is built, and therefore instead of so large a quantity of backing as will be necessary to make the whole good to that level with the land, I have proposed it to be built upon the back side as per section, Fig. 3. The rocks b. at the foot of the pier, are to be taken away as above shewn, before the



the pier is built; and when it is finished, they are to be cut off smooth according to the line a.

The bare stones of the pier (see the face view, Fig. 4.) are not proposed to be all on the same level, as there shewn, but the rock cut to give the stone its proper bearing.

The face (Fig. 4.) if you can procure the free-stone at a moderate price, will be best done according to the specimen; but if you work with rough stones, the more nearly they are laid conformable to the same idea, the better; and the platform at top should be laid on with the best mortar. As I cannot well judge of the prices at which the materials can be procured, and the work executed at Dunbar, I content myself with making an estimate of quantities as follows, which may be fitted up after proper workmen &c. are consulted.

ESTIMATES.

THE PIER.

£. s. d.

To cutting the rock according to the line in the plan 786 cube yards at -
 To building in the whole pier 2,770 cube yards at - - -
 To free-stone in the face and platform, reckoned at a medium $2\frac{1}{2}$ feet
 in thickness, reckoned extra in its value in the solid of the pier
 26,250 cube feet at - - - - -
 To posts of wood or stone (if thought necessary), as also for lime &c. -
 To contingent expenses at 10 per cent on the above articles - -

Total of the pier

£

THE GANGWAY.

To fir timber 942 say measured neat in place 1000 cube feet at -
 To iron work $19\frac{1}{2}$ cwt. say one ton at - - -
 To a large stone for fixing the end of the gangway to the parapet of the
 present pier, 30 cube feet at - - -
 Contingencies on the above at 10 per cent. -

Total of the gangway

£

PORT PATRICK HARBOUR.

The REPORT of JOHN SMEATON, Engineer, upon the Harbour of Port Patrick, in the Shire of Galloway, with a Projection of Piers for rendering the same safe and commodious for Vessels of eight feet draft of water.

THE harbour of Port Patrick is generally esteemed the nearest port in Great Britain to Ireland, being, as it is said, but about seven leagues from the harbour of Donaghadee, upon the coast of Ireland, and which is almost right opposite: on account therefore of the shortness of the passage, it becomes a very desirable object that the harbour of Port Patrick should be rendered safe and commodious for such vessels as are best adapted to carry the pacquets, passengers, carriages, horses, cattle and goods between the two kingdoms; and on this head I am advised, that nothing less than vessels of 40 tons, drawing eight feet of water, and constructed upon proper principles for sailing, will be fully adequate to this purpose.

The harbour of Port Patrick is at present entirely in a state of nature, a small platform for the more commodious landing and shipping of passengers, &c. excepted; and indeed it has many natural advantages, being very easy of access, and of sufficient depth to ride the vessels proper to be employed afloat at low water, and to protect them from storms coming from seven-eighths of the whole compass; and had the remaining eighth been as well guarded as the rest, this harbour had been complete; but the want of protection from those points, necessarily obliges the vessels employed to be of such a construction as unfits them for the general purposes. Those defects it is the business of art to remedy, which is the object of the present proposition.

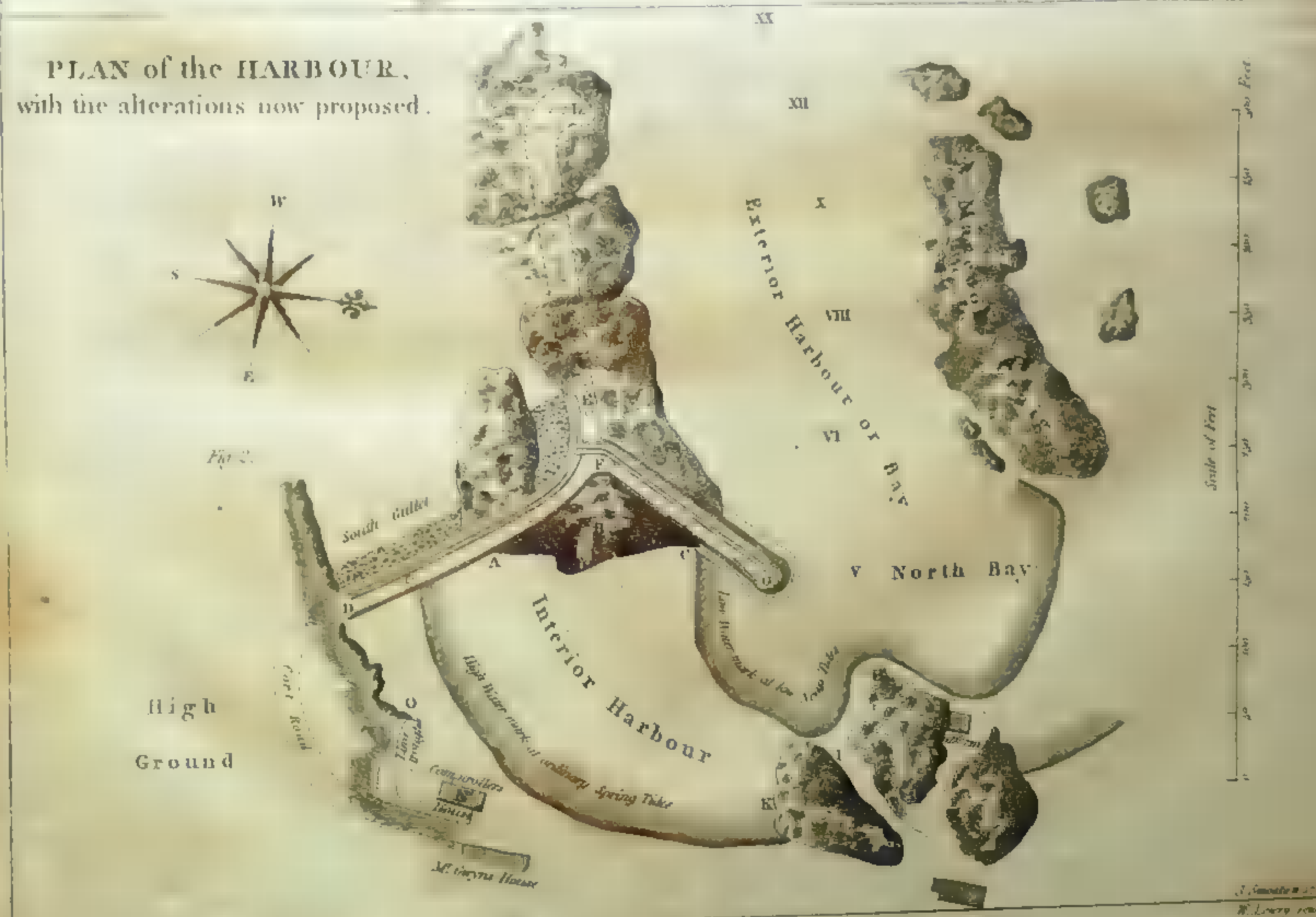
This harbour is formed by two ledges of rocks running out almost parallel from the shore, so as to form between them a small bay of about 220 feet clear width, and about 550 feet in depth, that is in and out. The bottom is a clean sand, and the soundings gradually increase from the shore to 20 feet at low water in the mouth of the bay, and leaving from 9 to 10 feet at dead low water mark in middle of the harbour.

The

PLAN of the NATURAL HARBOUR of PORTPATRICK with the PROPOSED PIERS by J. SMEATON, 1770.



PLAN of the HARBOUR, with the alterations now proposed.



The coast of Ireland lies right in front, extending from S. W. to N. W.,* and being so near as not to admit of any considerable swell with the wind right in, it becomes naturally defended from the western quarter. From the N. W. & N. points, the fetch of the sea is not of great lengths, being in a manner land-locked by the Illa, Mull of Cantire, &c. and being lastly very well screened by the ledge of rocks immediately on the north side of the harbour, which rise considerably above high water, no considerable violence is experienced on that side. The land lies from N. to S. so that nothing can happen from the eastern point; it is therefore only from S. to S. W. inclusive, that the harbour lies unprotected.

The ledge of rocks on the south side of the harbour, which run out in a direction W. by S. and nearly point toward the lighthouse of Donaghadee, would from their position afford a considerable shelter in all those winds, if they were higher; but the Irish sea being open from these points, and the rocks being in a great measure covered at high water neap tides, and at three-fourth flood at spring tides, the seas break over them with so much violence in time of storms, that vessels lying there are obliged to be suffered to beat up upon the sandy beach, at the bottom of the bay, and to be retained by ropes as the only means of protection; this in consequence not only creates a great deal of trouble in hauling them up, and launching them after the storms are over, but obliges them to be made so strong and of so flat a construction, that they will not fail except with wind on the beam or abaft. As therefore all the westerly winds prevent their sailing from Port Patrick to Donaghadee, and all the easterly from returning, it follows that they cannot regularly go and return except the winds are southerly or northerly; nor indeed could they go very well with those, were it not for the very strong current of the tides which set up and down this narrow channel, between the two kingdoms, twice each way in a day; so that by sailing at a proper time of tide, they are prevented by the current from falling to leeward: but could vessels constructed upon proper principles for sailing be protected here from all points, they would be enabled to turn to windward, and consequently make their passage good in all winds when the weather is moderate, from the great advantage that arises from the particular set of the tides.

Now, as this harbour in its present state would be very convenient for the purpose, being open and deep, and easy of access and departure, were it not on account of the effects of violent winds from one-eighth part of the compass only, as before mentioned, the place

* All the bearings in this report are according to the compass, the north point of which is supposed to vary about 24 degrees to the west.

itself being small, it must be a principal care, that while we are providing against the above mentioned difficulties we do not destroy its natural advantages. With this view I propose to run out a pier from the point of the rocks upon the main land at A. Fig. 1. Plate 6. and crossing the gully between that point and the detached ledge of rocks hitherto called the South Ledge, to follow the general direction of the same, and to terminate the pier at B. as particularly shewn in the plan. This pier to be raised six feet above the high water of a spring tide, with a parapet of six feet upon that; so that the whole being raised 12 feet above high water, will effectually screen the vessels from the S. & S. westerly winds, and greatly mitigate those nearer the west; and so far as this goes, the benefit to be obtained will be attended with no disadvantages in other respects, that I can foresee; and it is possible this being first executed, the internal pier may be found unnecessary; but as the north point of Strangford Bay on the coast of Ireland is the southernmost bearing from Port Patrick, viz. S. W. $\frac{1}{2}$ W. distant about nine leagues by the maps; when the wind is a little further out than this, viz. S. W. I am of opinion that so much sea will get round the head as to reduce the space naturally screened thereby into so narrow a compass, that vessels properly built for sailing will not safely ride in the harbour with the wind in such position, as may be judged of by considering the position of the line upon the plan, marking out the bearing of the north point of Strangford Bay. It seems therefore necessary to provide a place of safety at such times, which I propose to effect by means of the interior pier C. D. the position of which I have endeavoured so to adapt, as to be sufficiently capacious and deep, and without taking up any part of the external harbour, where I apprehend the vessels usually ride. This would have certainly been the case, had this internal pier been carried further out, so as to have been capable of admitting vessels drawing eight feet at low water; as it is, all the space is preserved where they cannot in ordinary float at low water, and vessels will be capable of going in and out of the external harbour at all times, except from three-quarter ebb to one-quarter flood; and during this space of low tide, the seas will be so mitigated by the projection of the rocks upon the neighbouring coasts, that a vessel may safely ride in the external harbour, till the water flows sufficiently to let her go into the internal. It is true, that as the vessels in the internal harbour will be obliged to take the ground, they will be required to be strong timbered; but as they are not intended principally to carry weight, that will not hinder their external form from being adapted in the best manner for sailing, it being the case with few harbours the most resorted to in Great Britain, that vessels can ride afloat at low water.

The flow of the tides at Port Patrick is said to be 15 feet at spring tides, and 12 feet at neap tides, but like other places variable according to the winds. When I was there, which

which was on the 11th of October 1768, being the day after the new moon, the perpendicular flow was only 10 feet, so that at a 15 feet spring tide the water would ebb out $2\frac{1}{2}$ feet lower, as appeared by a mark pointed out to me, and flow $2\frac{1}{2}$ feet higher; according to this state of the tides the internal pier will be placed at $4\frac{1}{2}$ and 5 feet water, at low water spring tides, and will have 19 $\frac{1}{2}$ and 20 feet at high water, and at such a tide as I saw (which was less than an ordinary neap tide), 7 and $7\frac{1}{2}$ at low water, and 17 and 17 $\frac{1}{2}$ at high water; so that it is evident vessels will be always afloat within the internal harbour, whenever it is a proper time of tide to go out, there being always 12 feet water at half tide.

This internal pier being at all times greatly sheltered from the violence of the seas by the external one, it is proposed to be considerably thinner on that account, and its body not raised so high by two feet, so that its top will be lower in the whole by four feet; that is, it will be only eight feet above high water spring tides; yet this it is presumed will always be fully sufficient to resist any seas that can get round the head of the external pier.

Since I have proposed the internal pier as a place of refuge, it may be reasonably enquired why this may not do without the external one? To this I must observe, that it is only so much of the external pier as projects beyond the internal one, that is the object in question; and this will be built with so much advantage to a proper height by being upon the rocks, that if omitted the internal pier will be required of greater base, height, and strength, and thereby the cost of the external one will in a great measure be incurred.

2dly. The vessels will be protected in the external harbour with wind at S. and S. S. W. and therefore can come in and find shelter, at a time when the tide would not serve to go into the internal harbour, and also will so far moderate the seas at S. W. as to enable the vessels to wait till they can get into the internal; and in all southerly winds will enable vessels to get under way going out, and to come to on entering, when they could not venture to do either from or to the entry of the interior harbour.

3dly. If the seas were not first moderated by the external pier, so much sea would get round the internal as not to admit vessels to lie there with sufficient quiet, unless it were so far contracted in the entry as to make it difficult of access and departure.

Within

Within the internal pier the vessels may occasionally take in their freight; but I apprehend the place of the present platform will be found in general the most commodious, especially about half tide, I propose that platform to be extended, and the face of the rock to be extended, by blowing off the irregularities according to the line E F. and if the rock G. and part of the rock H I. to that line, be blown up to the level of the sand, it will be a means of preventing damage to vessels within, and of entertaining a greater number of vessels, for when this is done, the interior harbour will be capable of holding, on occasion, 10 or 15 sail, from 40 tons downwards.

Respecting the construction of the piers, as the coast is all rocky, I propose to make all the use that properly can be done of the stone that the place affords, but it happens to be of a kind not very well adapted for this sort of work, except for fillings and rough basements of such parts of the piers as are not built upon the rocks, and to these uses I propose to confine it. The stone composing the two ledges of rocks on each side of the harbour is of a very hard but very jointy nature, which seems a good deal the case with the stone I see thereabouts, so that it can hardly be got without gunpowder, which would be apt to shiver it into small pieces. I observed that a considerable quantity of large loose pieces that have tumbled from the cliffs may be collected, enough to form the basements of the piers as marked out in the sections, Plate 5.; but as it does not appear that a sufficient quantity could be collected to do the whole with rough materials, which would, if so constructed be required to be still more bulky, I propose to face the upper part of the piers with quarried stones, scapelled to somewhat of a square form, to be disposed as shewn in the sections, and to be filled with rough materials to be obtained from the rocks in the neighbourhood. I did not indeed see any stone in that part of the country fit for facings of the kind I propose; but as this part lies open by sea to a considerable extent of coast of England, Scotland, and Ireland, it is not to be doubted but that convenient quarries of proper stone will be found that can be brought by water, and for this purpose I have made a consideration in my estimate of 2s. 6d. per ton, that will be about 2d. per cube foot, which allowance I judge fully sufficient.

It is further to be observed, that I propose all the rough bases and fillings to be composed of as large stones as can easily be procured near the place, and no stones of two tons or under be broken on account of removal; and that the fillings be at a medium, about a cube foot in a piece, the smaller being disposed in the interstices. The whole to be built dry, except what is particularly specified in the estimate to be done with cement or mortar.

It

It has been observed to me that a considerable rivulet can be turned into this harbour; this may be of great use in case the interior harbour shall be found inclined, from a greater degree of confinement, to retain more sand than it does at present, and will prove an effectual remedy to every evil that can arise from that circumstance. At present the harbour does not retain more sand than one would wish it to do, for the safety and ease of vessels.

Authorpe,
18th May 1770.

J. SMEATON.

EXPLANATION of the Plan of Port Patrick Harbour.

Fig. 1. (Plate 6.) Plan of the natural Harbour, with the projection of the proposed piers:—The Roman figures express the depth in feet of the low water of a spring tide, the perpendicular rise of which is said to be 15 feet and the neap tides 12, consequently at neap tides low water, there will be 1½ feet more water than the soundings express. The bottom is clean sand.

AB The exterior Pier.

CD The interior Pier.

EF The line in which the face of that rock is proposed by blowing to be straightened, and to have timbers bolted to the face of it, to make the landing place there more commodious; the platform may also be extended to *c. f.*

G A rock to be blown to the level of the sands; and

H I Another to be blown to this line, in order to clear the interior Harbour.

The line KL shews the bearing of the north part of Strangford Bay, upon the coast of Ireland, being according to the map 9 leagues distant.

Fig. 3. (Plate 5.) Shews the outward face of the Pier on the south rocks; and

Fig. 4. Do. A section of the same, shewing the manner of building it with quarried stone, and filling up with rough stones.

Fig. 5. Do. Section of the Pier across the gully, between the south rocks and the shore.

Fig. 6. Do. Section of the interior Pier:—All these figures are placed to shew their relative levels to high and low water lines (A & B) at spring tides.

ESTIMATE for building the Piers of the Harbour of Port Patrick, according to the designs of John Smeaton Engineer.

The EXTERIOR PIER.

To form a basement of rough stones, to be collected from the adjacent coast and cliffs in order to make up the gully between the main land and the ledge of rocks on the south side of the Harbour, to be 32 feet mean base, 24 feet top, and 8 feet mean height, length 120 feet, will contain 1000 cube yards, which at 7s. 6d. per yard	-	-	375	0	0
The upper part of the Pier being supposed a masonry 18 feet high, extending from the land 400 feet; the mean thickness of the facing on the outside of the Pier being 3 feet 3 inches, and the inside 2 feet 9 inches, will contain cube feet	-	-	24,000		
To make good the platform at top, being the same length, 12 feet broad and 1 foot thick	-	-	4,800		
Cube feet of stone at 10d. per foot complete	-	-	28,000	1,200	0 0
To 2,044 cube yards of rough stone in filling, at 5s.	-	-	511	0	0
The circumference of the Pier head for 40 feet in length next the head, will be 112 feet, this at the mean thickness of 3 feet 6 inches, and 10 feet high, will produce cube feet	-	-	3,920		
And to make good the platform to the above	-	-	1,120		
Cube feet of stone at 10d. per foot	-	-	5,040	210	0 0
To rough stone in filling 40 feet length, next the head, 332 yards at 5s.	-	-	83	0	0
The length of the front wall of the head being 40 feet, 15 feet in thickness, and 10 feet high, contains 222 cube yards; this being laid in cement, will, with extra labour and materials, at 7 shillings, come to	-	-	77	14	0
To cutting footings for the bases of the outside casings to rest on, 1,540 feet superficial, at 1 shilling	-	-	77	0	0
To 440 feet of parapet in mortar, at £1. per foot	-	-	440	0	0
			£ 2,973	14	0

The INTERIOR PIER.

To the forming a basement without the rocks of rough stones, 33 feet base, 25 feet top, and 9 feet high, supposed to reach one foot above low water, and to settle 3 feet into the sand; this, in a length of 180 feet will contain 1,740 yards, at 7s. 6d.	-	-	652	10	0
The height of the casing being 18 feet mean thickness, of the outside 18 feet 9 inches and 1 foot 9 inches, inside 2 feet 4½ inches; this, in a length of 180 feet, will contain cube feet	-	-	16,605		
The height of the casing over the rocks to join the former to the main pier, being 8 feet, will at the above thicknesses and 70 feet long contain	-	-	2,870		
To make good the platform in the whole length	-	-	2,500		
			21,975	915	12 6
To rough fillings in that part of the Pier without the rocks, cube yards	-	-	1,658		
To Do. in the part over the rocks	-	-	210		
Cube yards of rough filling, at 5s.	-	-	1,878	469	10 0
To cutting the footings upon the rock, 280 feet, at 1s.	-	-	14	0	0
To walling 5 yards, running next the head, in cement, containing 200 cube yards, extra labour and cement, at 7s.	-	-	70	0	0
To 240 feet of running parapet in mortar, at 15s.	-	-	180	0	0
The Interior Pier	-	-	£ 2,301	12	6
The Exterior Pier	-	-	2,973	14	0
Neat computation	-	-	£ 5,275	6	6
To contingent expenses, in iron work, fender piles, stairs, blowing of rocks, machines, &c. being 10 per cent. upon the above	-	-	527	10	0
			£ 5,802	16	6

Authorps,
18th May 1770.

J. SMEATON.

EXPLANATION of the Plan for completing the Interior Harbour at Port Patrick.

THE work being now advanced sufficiently to the west to break off from that part intended for the interior Harbour, the great seas that roll in with the southerly and south west winds, what is principally wanted to secure the vessels lying under shelter of the present work, is a flank Pier to prevent the seas from returning laterally after they have passed the head, and then following the back side of the Pier and ledge of rocks into the place of the interior Harbour.

For this purpose, and by reason that it is found expedient to complete the interior Harbour before the exterior Pier is carried further out, I have projected the Pier designed in the present Plan in such a way, as that it may in the best manner answer the end, on supposition that it may not be found expedient to carry out the external Pier further than it extends at present.

I have therefore designed it in such a position that vessels, when coming from sea, may run into the interior Harbour under sail, leaving the bottom of the little Bay Road Stead or exterior Harbour as disencumbered as possible, to be used in moderate weather, and when a greater degree of shelter and protection is not necessary for the same purpose at present; and at the same time having the access to the interior Harbour as free as possible, that time may not be lost in getting in and out of it.

The position of the proposed interior or flank pier, is nearly N. E. by the compass, and extended from the main pier 175 feet, so as to leave about 100 feet of opening between the Pier head and the nearest point of the platform rocks, which rocks will in effect answer the end of a counter pier. This position and length, by admitting of an opening of 100 feet, will enable vessels to get under sail in bad weather, that is, whenever they can venture in between the two ledges of rocks that compose the exterior harbour, and will prevent the lateral return of the southwest seas into the interior harbour, and throw them into the bottom of the north Bay, so as to spend themselves upon the beach. It is in conformity with this position of the Pier, and in order to afford room within the harbour, as well as to give the whole of the inside such a curve as may more effectually clear off the sands that may occasionally be brought in, that it is proposed to cut the rocks to the arch ABC. (Plate 6. Fig. 2.) It is also with this view that an opening of 100 feet is proposed to be left; for though it will always hold true, that the less the mouth of a harbour is, the quieter

quieter it will be proportionably within; yet as the getting clear of sand, the getting safely in during bad, and easily out in moderate weather, are considerations of the greatest consequence; and it being impossible in small harbours to unite every advantage, it seems to me that the present plan will be likely upon the whole, to answer the end in the completest manner possible; that is, for sheltering vessels from 30 to 40 tons and under, which it is supposed will be fully sufficient for the packet and passage vessels attending at this place.

At present I understand that the place of the interior harbour keeps itself as clear of sand as is necessary, that the rocks may not become bare, and the vessels lie unsafely; but when it becomes more inclosed by the erection of the flank pier, as it may not then clear itself of sands so effectually, the bringing in of the burn occasionally in the way that has been already mentioned, by the garden. The collector of the customs, I do not doubt will be effectual to keep it clear.

I have also endeavoured to make the pier subservient to some purposes, which, though subordinate, will yet be found very convenient if not necessary.

I have proposed to terminate the parapet by a round pillar of nine feet diameter, at the top of which may be planted a flag-staff in order to hoist a flag when there is a certain number of feet of water within the pier head, or by planting a light in a lanthorn or lamp fixed upon a proper iron stanchion, vessels approaching in the dark will not only with more certainty make the bay, but turn the pier head in case they wish to enter the harbour.

I have also designed a stair near the pier head inside, to which a boat can always go even at low water, and thereby passengers be commodiously conveyed on board or landed at all times of tide. Mooring posts are also proposed and marked at proper intervals; and as a post near the extremity of the main pier may be very convenient for the fastening or steadying vessels in the bay or exterior harbour, a passage is purposed to be made by an archway of two feet and a half wide, and four feet and a half high, at the joining of the flank pier's parapet to the present one.

The spring tides are said to flow here 15 feet, so that there will never be less than eight feet water within the pier head at half tide.

N. B. The projection of the main pier westward of the junction of the flank pier, will greatly contribute towards breaking off the seas from the harbour's mouth.

J. SMEATON.

Authorpe,
6th January 1774.

P. S. It may be problematical till the flank pier is far advanced, whether it may be better to cut off the point of the rock marked I K. Fig. 2. by the dotted line or not. It will undoubtedly render the passage in more perfectly clear if cut away; but as it may tend to catch the swell that will in some degree roll in between the pier head G and the point of the rock H, this operation is left till the effect of the flank pier is seen.

EXPLANATION of the Plan, Fig. 2. Plate 6.

- A B C The line to which the rocks are proposed to be cut away.
 D E The present pier as now terminated.
 E L The extension as at first proposed.
 F G The interior or flank pier as now proposed.
 G H The opening between the pier head and the nearest point of the platform rocks, being about 100 feet.
 I K A line in which that point of the rock may be cut off, in case it shall be found useful when the effect of the flank pier is seen.
 N. B. The Roman figures shew the foundings in feet at low water mark.
 N Comptroller's house. O lime troughs.
 Fig. 7. (Plate 5.) A plan of the intended pier F G in Fig. 2. Plate 6.
 — 8. Elevation of the same.
 — 9. Section of the same.
 A B Is the breadth of the pier upon the rough ground basement 40 feet.
 C D The breadth of the rough ground basement at about one foot above low water, 32 feet.
 E F The base of the pier at the bottom of the freestone work, 27 feet.
 G H Shews the top of the cap or platform of the pier, 18 feet.
 a b Fig. 9. the supposed surface of clay or hard matter.
 c d Supposed surface of the sand.
 X Y Z Fig. 8. The terminating pillar of the parapet capped with three circular stones, the two upper ones are supposed to be each single stones, the lower one of 2, 3 or 4 pieces, as most convenient, the rest of the pillar to be built as the outside of the parapet.
 L N Fig. 7. shew the stairs inside the pier head.
 O P Q R Shew the manner of forming the cap of the pier, being terminated with dovetailed stones in the manner of the Edystone, to bind the cap together.
 M A post or pillar for warping vessels into and out of the harbour.

DIRECTIONS to Mr. GWIN, for the execution of the interior or Flank Pier for completing of the interior Harbour of Port Patrick.

THE middle line of direction of the base of this pier runs from a point about 45 feet from the westernmost termination of the top of the present pier, measured inside toward the east to another point about three feet from the southwest angle of the platform, measured along the south side, also toward the east, which line of direction will be nearly N. E. by the compass; and as the width of the pier at its base will be 40 feet, it will be proper to fix up leading marks from the present pier to the shore parallel to the above mentioned middle line of direction, at the distance of 100 feet on each side of it, so that a person standing at either end of these leading marks may be able to direct a person on board a vessel afloat, to drop stones in those lines, which are to form the extremity of the base.

It will be proper to have the stones so to be dropped (which are to be large pieces of rough rocks) suspended by tackles in slings, yet not to hook immediately by the slings, but by a loop made of as many turns of marline or rope yarn as will hold it, and then by cutting the loop when the stone is in its proper position, it will be sure to be dropped in the outline. The stones to form the internal part may be any how tumbled overboard, so as to be within the area formed by the outlines.

It is supposed that the first and perhaps the second set of stones so dropped will bury themselves in the sand, and the sooner or later according as there is more or less surge of the sea breaking upon the place where they are deposited; but notwithstanding the first, second, or third set of stones disappear, yet by repeating the dropping they will at last ground themselves upon the clay or gravel, and those dropped upon them begin to appear above the sand, and at last above the surface of the water at low water. But it is to be noted, that every subsequent set of stones dropped to form the outline, must be nearer the centre line than the preceding, so that a slope somewhat like that shewn in the section may be formed. As to the interior parts they may be tumbled in promiscuously, and if they begin to appear in some places before others, the defective places may be afterwards supplied. The more rough weather you have in the course of making this basement, the more solid your work will be, as it will be the more firmly or the more deeply grounded upon the harder matter, and prevent after settlements, and in case any part of the work settles after it has appeared you must still fill up the addition by fresh matter.

The

The diameter of the circular part of the head being two feet greater than the common breadth of the pier, the basement may be broader by one foot and a half each side, that is, 43 feet over all; and having determined the extremity of the basement of the head by cross marks at or about 88 feet from the nearest point of the platform rocks, this cross line with the others will be sufficient for dropping the foundation of the head in somewhat of a circular form, correcting it as you see it, for when you get the pier head to appear above low water, you then can mark off an actual centre and work by real lines.

As you have not said at what depth below the surface of the sand you found the clay, gravel, &c. I have supposed in the additional drawing, Fig. 7 & 8, (Plate 5.) that the sand lie three feet and a half below the surface of the water at low water, and the clay three feet and a half below the sand, so that from the solid matter to low water mark is supposed 7 feet; if it happens to be more in any or every part, the width of the ground tier of stones must be proportionably increased; if less, you may diminish it at discretion, but in general it is good to keep a good breadth upon the ground.

It is probable that at low water you will find the stones stuck in the sand, so that you may be able to borrow away your slings; but if you find the stones to bury themselves, you will save expense by procuring old cordage to make them of.

On supposition that the stones in still weather do not bury themselves, if you can at low water give them some assistance it may not be amiss; but at any event, the piling a weight of stones upon them will, with the aid of the action of the sea, cause them to settle, and at last to ground themselves.

Supposing this to be an operation that would occasion the foundation to go on for more than one year, the best way would be to carry on the work progressively from the rocks towards the head, as by that means every part would have time to ground, while the part beyond it was advancing; but as the whole at least of the basement is expected to be completed in one season, to give it all the chance possible of storms to make it ground, I am of opinion, that you should begin with the head, and go on to complete the rough basement between the head and the rocks, so as to bring the whole to a level about one foot above low water, and then go on with the upper works (the outsides of which are to be of scapped blocks) to proceed progressively from the rocks towards the head, for by this means the head, whose firm establishment is of the principal consequence, will have the greatest share of time to come to a firm bearing; and when you cannot on account of the tide work below, you may be employing the people in getting the work forward that is upon the rocks.

Your

Your first work will be during the winter to provide all the large rough pieces of rock you can procure, in order to make the rough basement, and as far as may be convenient to get them brought to the place.

In regard to the masonry of the upper works, as the turning of the head cannot be done otherwise than with stones upon their flat beds; and I never intended this interior pier to be built otherwise than with the stones upon their beds, the distance between the head and the rock will be so short, that it will be hardly worth while to change the masonry; however, if you find any convenience in the diagonal way of working for the outside, you are at liberty to put it in practice.

The whole I propose to be built dry till you come to lay on the platform or top of the pier, after which you will proceed with mortar as usual. As the joints of the stones in turning the head of the pier will be radii, or pointed to the centre, and will have nothing naturally to retain them from getting outward but their own weight and the incumbent weight of the matter above, it will be proper to cramp them every third course, or otherwise to retain them to the more central parts by iron doggs. And by way of securing the platform or cap of the pier head, which will be the most apt of any other to get loose, and at the same time to make it a firm tie upon what is below, I propose the work thereof to be jointed dove-tail-wise in the Edystone fashion, as shewn in the additional design, Fig. 7. Plate 5.

If you find it adviseable by way of tying your work faster together to begin with mortar above high water, for some of the last courses next the platform, and can procure lime with pozzelana, I shall have no objection; but if this will embarrass the work, I do not hold it to be absolutely necessary.

Austhorpe
6th January 1774.

J. SMEATON.

N. B. As the high and low water lines are not certain determinate heights, you are to be guided by the pier already done; the cap or platform of the flank pier, and the top of its parapet, being respectively of the same height as the present pier.

RAMSGATE HARBOUR.

(See the Plan, Plate 7.)

An Historical REPORT on Ramsgate Harbour, wrote by order of and addressed to the Trustees, by JOHN SMEATON, Civil Engineer, F.R.S. and Engineer to Ramsgate Harbour, 1791.

To the Trustees of Ramsgate Harbour.

SIRS,

THE following piece was begun last year by your order, principally with a view to inform the public of the improved state of Ramsgate Harbour, and of the Improvements that were in a way to be further brought about; as also of the unexpected difficulties that had occurred in the progress and actual execution of this long desired establishment.—Indeed the small length of time that it had been a Harbour, capable of fulfilling the purposes for which it was begun, had scarcely given opportunity to the maritime part of this Nation, and more especially to foreigners, to acquaint themselves with the advantages they might derive from the use thereof.

It is now somewhat more than ten years since Ramsgate Harbour was so far cleansed of sand and silt, as to be capable of taking in ships of superior draught of water and tonnage, to what appears to have been the object of Parliament in granting the act, as well as to the views of the original promoters of the undertaking; yet it was not till the winter before the present (January 1790), that the real practical utility of this Harbour appeared in full view, for it had so happened, that the same means that had been necessarily employed for cleansing it, (that is to say, for constituting it a Harbour), had subjected it to that kind of agitation and inquietude, which in general rendered it more eligible for vessels of burden, such as might very well have come in as to draught of water, to subject themselves to the wear and tear of their tackle, and the risk of riding it out in the Downs, than come into the Harbour till they had received some actual damage.

The quietude of the Harbour has at length in a great measure been happily effected, along with the other advantages, by the progress made in the construction of an advanced pier. This was only begun in the summer of 1788, and at Christmas 1789 was run out the length of 120 feet, that is nearly one third of its proposed length; which so sensibly

sensibly quieted the Harbour, that in January and part of February 1790, there were in it no less than 160 ships and vessels that came in for refuge, and to save the wear and tear of their tackle and furniture, all of which must otherwise have crowded the Downs.—Almost an equal number, for the same reason, came into the Harbour during the tempestuous weather of the past January.

It may however possibly seem to some, that the means now taking to quiet the Harbour may operate to render it less accessible: but this, when properly understood, will not appear to be the case, but so far otherwise, that in reality a ship will come in with greater facility; for the Harbour's mouth is in effect as wide as it was before the advanced pier was begun.—The original width of the Harbour's mouth, as intended, was 200 feet; the opening to be at S. S. W. The width ultimately fixed by the Trustees was 300 feet at S. $\frac{1}{2}$ E. but that width and position appear to have been settled at a time when the Trustees were apprehensive of the Harbour entirely choking up with silt, if more inclosed, and not from any necessity of that width, merely for the sake of facility of entry; 200 feet clear opening being deemed a large sufficiency for the entry of an artificial Harbour, entirely raised out of the sea by the hand of man.

When the Harbour was formed, it was found that during all the time of full sea, a strong current sets almost right across the Harbour's mouth, that is, from west to east, which being a natural cause, cannot be diverted; a vessel therefore coming from the south, that is, from the Downs, were she to attempt to run into the Harbour, right across the current, would be carried eastward thereof, so as to miss it: it has therefore been an established maxim, ever since the Harbour was formed, and given out as a direction, for vessels to come in obliquely from the westward, and as close as properly may be to the west pier head; and this course, as marked out many years ago upon the plans of direction, will carry a vessel right through the present intended opening, betwixt the west head and the head of the advanced pier, which is full 200 feet in width, and she will always come in with the tide in her favour.

In consequence of your orders, in the course of last summer I made a considerable progress with this Report, intending to have completed it at leisure this spring, but if by being called upon more hastily than I had expected, it comes out less finished than I could have wished it, I have this only circumstance to plead in my excuse.

I remain, Sirs, &c.

J. SMEATON.

SECTION I.

ACCOUNT of early attempts towards a Harbour for the Downs, and of proceedings, inclusive of obtaining an Act of Parliament, for establishing a Harbour for that purpose at Ramsgate.

THE expediency of a Harbour for the reception of Ships in the Downs, has doubtless subsisted as far back as the increase of our trade and shipping has rendered it important; but the want of a situation strongly pointed out by nature, was probably the reason why we have not heard of any attempt towards it in the earliest ages.

In the time of King Edward 6th it is said there was an attempt to make a Harbour from Sandwich into the Downs, and that the existing traces of a canal, which still subsist in the level grounds, between Sandwich and Sandown Castle, are the remains of that attempt. It is also said, that commissioners were appointed by Queen Elizabeth in 1574, for taking a survey of Sandwich Haven, and to give their opinion as to the making a better Harbour near Sandown Castle. Also that in 1706, a plan, report, and estimate, were delivered by persons appointed to survey and estimate the expense of a new Harbour from Sandwich into the Downs, accompanied with a certificate of the Flag Officers, and many commanders of the ships of her Majesty's royal navy, who then gave it as their opinion, that such a Harbour might be of general advantage to the public.

It seems also that petitions were presented to the Honourable House of Commons, praying for a new Harbour near the Downs, April 2d 1736; and that a committee appointed by the House heard evidence upon the matter thereof; and that in consequence a plan and survey of the Downs and coasts adjoining, were undertaken by Mr. Labelye, afterwards Engineer to Westminster Bridge, at the expense of Sir George Oxenden Baronet and Josiah Burchett Esquire, then members for the town and port of Sandwich; a copper plate of which was published in 1737-8, in which he exhibits a scheme for sheltering ships from the Downs by a navigable canal and basin, in the very direction of the Old Cut above mentioned, and by sluices to join the river Stour.

In April 1744, the House of Commons presented an address to the King, "that he would give directions to proper and skilful persons, to view the Haven of Sandwich, and examine whether a better and more commodious harbour may not be made into the Downs near Sandown Castle, fit for the reception and security of large merchant ships and men of war; and to survey the said ground and shore; and also the river Stour, necessary

sary to cleaning and scouring the said Harbour when made; and to make an estimate of the charges and expenses thereof;" to be laid before Parliament the ensuing session.

In consequence of the above, an order was issued from the Admiralty, appointing the following persons to this business; W. Whorwood, John Redman, John Major, Thomas Slade, Charles Labelye, and R. Charles; who reported, that having made the necessary observations, "a better and more commodious Harbour, than the present haven of Sandwich, may be made from the town of Sandwich into the Downs near Sandown Castle."

They proposed to carry out two stone piers, each 2,096 feet in length from the shore, into twelve feet depth of water at low water, to have a clear opening between the heads of 300 feet; to narrow from that to 100 feet; and that the middle line should point S. S. E. $\frac{1}{4}$ E. by the compass; that is nearly S. E. by the true meridian, or S. S. E. as the compass now points. The estimate for this work was £.389,168. 13s. 2d. exclusive of the value of the grounds to be purchased.

The report being referred to a committee of the whole House of Commons; after examining evidence of pilots and persons best skilled in the navigation of the Downs, the committee came to a resolution, dated the 26th February 1744-5, importing, that it appeared to them, "that a safe and commodious Harbour may be made into the Downs near Sandown Castle, fit for the reception and security of large merchant-men and ships of war of sixty and seventy guns, and be of great use and advantage to the naval power of Great Britain.

Why this great work was suspended, after being brought this length, does not now distinctly appear; but if we consider the largeness of the sum estimated, for a work supposed to be undertaken by Government, at a time when we were at war with France and Spain, we perhaps need not be at a loss to judge.

The whole affair seems however to have lain dormant for some time, till the public was roused by a violent storm which happened on the 16th December 1748, wherein a great number of vessels were driven from their anchors in the Downs, and being forced upon the south coast of the Isle of Thanet, several found safety in the little harbour of Ramsgate.

This

This seems at once to have opened the eyes of the public, and caused them to be turned upon Ramsgate as the proper place for the reception of ships when in distress from bad weather in the Downs; and accordingly, the 8th February following, a petition was presented to the House of Commons, by several merchants of the city of London, owners and masters of ships, whose names were thereunto subscribed, amounting to 131, which was referred to a committee appointed to sit the 13th following; and on this day a petition was presented from the mayor, magistrates, freemen and inhabitants of Sandwich; setting forth the damage that would be likely to arise to the haven and port of Sandwich from the extension of piers into the sea at Ramsgate, which was referred to the same Committee.

In support of the Petition of the merchants, owners, and masters of ships, a great number of witnesses were examined, and to a considerable length: and the following points were fully and clearly proved, to the satisfaction of the Committee.

1st. That, in the said great storm of December preceding, a number of ships were actually forced into, and saved in Ramsgate Harbour, although then so small as to be scarcely capable of receiving vessels of 200 tons, at any time of tide; that pier having been only built and maintained by the fishermen of the place.

2d. That the winds in the Downs, whereby ships riding there are most apt to be annoyed, are from S. S. E. to S. S. W.

3d. That at Ramsgate, or near it, was not only the best, but in reality the only place, where any harbour could be built, that could be serviceable to ships in distress in the Downs, because Ramsgate was right in the lee of that road, with such winds as produced that distress; and at such a proper distance, that, after driving or breaking loose, they had time to get under sail, so that with a slender share of seamanship they could make a harbour if built there.

4th. That though this shore was universally flat, yet as it gradually increases in depth from the Cliffs towards the Downs, it was practicable, at a moderate expense, to carry out piers into six feet and a half water, at the low water of a middling spring tide; and that, according to the rise of the tides, there would be water enough from three-quarter flood to one quarter ebb even at neap tides, to carry in vessels drawing fifteen feet water, which, if full built, was supposed to be full 300 tons burthen.*

* I understand it can be made to appear that more than two-thirds of all the tonnage and value of shipping is carried on in vessels not exceeding 300 tons.

5th. That

5th. That when vessels break loose from their anchors in the Downs it is generally from three-quarter flood to one-quarter ebb,* during all which time the course of the current of the tide is to the North and N. E. which therefore would carry them right into a harbour at Ramsgate, so that by the time they got thither, it would be within an hour of high water.

6th. That the soil at Ramsgate being a chalk sufficiently firm to build upon, but yet so yielding that the keels of vessels readily make a dock for themselves therein; this, with sometimes a slight cover of sand, forms a proper bottom to lay full built ships aground upon at low-water; and even if sharp built, will, in case of necessity, subject them to the least possible damage; and indeed to little or none, if proper precaution be taken to lay them against a pier; nor can they suffer the least, if a proper basin be constructed to lay them afloat.

7th. That in time of war merchant ships are built sharper than in time of peace; but that at an average more of the London traders are built full than sharp.

8th. That the great ships in the Downs are obliged to ride in a bad road to be out of the way of the small vessels, which commonly lie in the small Downs, and those small vessels being often ill-furnished with anchors and cables, frequently break loose, and drive upon the large ships, which then run foul of each other; whereby sometimes a whole fleet is set adrift; and in the opinion of Captain Conway (then an elder brother of the Trinity House) if a harbour were only made for the reception of ships of 200 tons and under, it would prevent nine-tenths of the damage that happens in the Downs; as he supposes all ships under 200 tons, waiting for a wind to proceed westward, would take shelter therein.

9th. That ships in Ramsgate Harbour may sail out of it with any wind, that would carry them westward out of the Downs; and even with a strong wind at east, or with a scant wind at S. E. by E. they can make good their course out of Ramsgate Harbour, by virtue

* This will appear clearly to be the case, when it is considered that they are the Goodwin Sands that constitute the Downs to be a road for ships. At low water those sands may be considered as a pier or break-water to all the easterly winds; and even at high water, it is too shallow over them to admit the great seas to pass, without being much broken and dispersed, especially in stormy weather. From the situation therefore of the Downs, these sands on one side, and the coast of Kent on the other, it is only the southerly winds that can annoy them, which also are much moderated by the proximity of the coast of France; and still more so, by the first part of the flood tide running southward, and meeting the seas; it is therefore not till the tide turns to the north (which is at or about three-quarter flood) that the combined force of wind and tide, makes the great effort to break the ships from their moorings.

of the flood tide, under their lee, and sail westward, when ships in the Downs cannot purchase their anchors.

10th. That large craft might be constantly kept afloat in Ramsgate Harbour, at low water, such as might be able to carry out pilots, anchors, cables, and other assistance to men of war and large ships in distress in the Downs;* and the matter is so circumstanced that whenever they could not go from Ramsgate, boats may go out from Dover to ships in the Downs.

Upon this evidence, which I have carefully extracted from the Committee's report, I only beg leave to observe; that the tides, the sands, and the coasts remaining the same, as also the natural powers, what was true in the year 1749 will remain true in the year 1791.

During the whole of this investigation the great project of a harbour at Sandown Castle seems to have been altogether lost sight of; and perhaps at this we may the less marvel; if casting our eye upon the position thereof; vessels breaking loose from their anchors there, with wind at any point from S. S. E. to S. S. W. would be driven to the leeward of the harbour's mouth before they could get under way, so as to be under dominion of their helm; and therefore, after all, liable to be wrecked or run ashore upon the south coast of the isle of Thanet †.

Nor indeed, according to my judgement, could a more injudicious construction than the piers proposed at Sandown, be well imagined; for the heavy seas that would fall in between the heads (that is, all those producing distress in the Downs) would be so augmented by the gradual contraction of the distance of the piers, from 300 feet at their entry, to 100 feet near the basin; that vessels would not only be liable to be wrecked between the piers, but those augmented seas would infallibly destroy the gates of the basin; and

* Such crafts and pilots now actually station themselves at Ramsgate, and are the means of saving many lives and much property.

† While the investigation for a harbour at Sandown Castle was going on before Parliament in 1744, reasons were offered against making a harbour near Sandwich; to which at that time no regard seems to have been paid, viz. Sandwich having no convenient outlet for ships bound to the westward, they must remain wind-bound with many fair winds. 2dly. The inlet is inconvenient to receive ships bound to the westward, which are detained in the Downs by contrary winds and stormy weather; for if any ship's anchor start, or cables give way, they must drive past the harbour, before the ship can be brought into a position to put for the entrance.

probably

probably the fixed part of the stone work also.—It hence appears most evident, that nature has not in reality furnished any situation for a harbour for the Downs preferable to that at Ramsgate; and therefore we need not wonder, that the project of the long-wished for harbour for the Downs was at that time promoted to be at Ramsgate, with a degree of eagerness and even of enthusiasm.

The Act passed that session, setting forth in its preamble, "Whereas frequent losses of the lives and properties of his Majesty's subjects happen in the Downs for want of a harbour between the North and South Forelands; the greatest part of the ships employed in the trade of the nation being under a necessity of going out upon as well as returning from their voyages, to pass through the Downs; and frequently by contrary winds being detained there a long time; during which time (especially the outward-bound ships) are exposed to violent storms and dangerous gales of wind, without having a sufficient harbour to lie in or retreat into, or from whence they can receive any assistance: And whereas a harbour may be made at the town of Ramsgate proper and convenient for the reception of ships of and under 300 tons burthen; and from thence larger ships in distress in the Downs may be supplied with pilots, anchors, cables, and other assistance and necessaries; and by the smaller ships taking shelter in this harbour the larger ships may take the anchorage which at present is occupied by the smaller, and by that means their anchors will be fixed in more holding ground, and the ships not so exposed to the ocean; for carrying therefore a work of such public utility into execution, &c. be it enacted," &c.

The first meeting of the trustees was appointed at the Guildhall London the first Tuesday in July 1749, (that was then next following), at which a large number named in the Act, to the amount of sixty-six, appeared to qualify.

SECTION II.

PROCEEDINGS of the Trustees from the Commencement of the Work in 1749, to the total Stoppage of the same in 1755; upon Petition to the House of Commons.

THE first act of the trustees regarding construction was to appoint a Committee of their body to view the place at Ramsgate, where a new harbour was intended to be made; and report their observations and opinions to the trustees at their next meeting; and

and that Mr. Robins and Mr. Turner of Gosport should be desired to attend them ■ engineers.*

The Committee accordingly met at Ramsgate, and on their return, reported, that in consequence of objections having been made before the Committees of the House of Commons to Ramsgate, for want of a back-water, they having examined found from information, that in the year 1715 the pier then standing had been lengthened; and by inspection it appeared, that a bar of about forty yards breadth and length had been cast up, its highest part in thickness two feet and a half; and they considering this small quantity as the gradual effect of 34 years, thought it reasonable to expect, that when a greater depth of water was made by two piers instead of one, the filling up by fullage or beach would become so inconsiderable, that a small expense would continually prevent its increase.

They further observed, that the seaweed or fullage that drove in, came from the westward; and that from the east there was a drift of large shingle; which if it should take place, would be of advantage in backing the new piers. They also made and reported many other observations confirming what was given in evidence before the House of Commons in its favour.

They endeavoured to fix their opinions as to one material point, which could not be so conveniently settled in evidence before the House; and about which there was some diversity of opinion; and that was the position of the harbour's mouth, whether South, S. S. W. or S. W. were to be preferred. Towards the resolution of which question the committee premised, "that the stream of the tide in the Downs sets for six hours to the northward, or at least between the north and the east, and then for the next six hours the stream turns and sets to the southward, or between the south and the west; but the time of high and low water does not correspond to the beginning and end of these streams; for it is high water about two hours after the stream has begun to run to the northward; and it is low water two hours after the stream has set to the southward, so that when the tide first sets to the northward, more than two thirds of the tide has flowed; and high water happens about two hours after:" and that having separately examined eleven captains or masters of ships of Ramsgate, they all unanimously agreed, that the most dangerous winds in the

* It may at this day seem extraordinary, why Mr. Labeledge, who appears to have made the original plan, upon which himself and associates proceeded as mentioned above, should not have been called upon and consulted in this latter stage of the business; but if it be remembered that in the year 1748, one of the piers of the new bridge of Westminster, built under his direction, most unfortunately settled, so as to oblige two of the arches to be taken down, after the bridge had been opened to the public, we may be the less surprised.

Downs were from the S. S. E. to S. S. W.; and that the time when ships run the greatest risk of being forced from their anchors, is when the northward stream sets in; and that about the same time, that is the beginning of the northern stream, was likewise the most prudent for such ships as should intend to make for Ramsgate harbour, to slip their cables; for, that in either case, they would have both wind and tide in their favour, in standing for Ramsgate; and that on their arrival, they would find it near high water, allowing an hour for their passage: and they unanimously agreed, that ■ entrance to S. S. W. was to be preferred: for if placed full south, the tide near high water would run so strong across it, as to render it difficult to get in; and if at south-west, they feared there might be too great an indraught of fullage. All the bearings then referred to were settled by the compass, which in the Downs was then $1\frac{1}{2}$ point west.

They also particularly attended to the point, whether the piers should be built with wood or stone; but agreed unanimously stone was greatly to be preferred, had it not been for the great difference of expense, especially as they had found (and brought up specimens) that the worm bit considerably in the pier then standing. On the whole they were satisfied, a harbour at Ramsgate would be ■ practicable, useful, and important, as they had before thought; and concluded with observing, that no other motive than that of avoiding expense should have any weight in assigning to this harbour a form less perfect or extensive than it was by nature capable of receiving. It does not, however, appear that the Committee, on this occasion, were attended by Mr. Robins or Mr. Turner.

The next step of the trustees was to advertise to invite engineers to deliver plans sealed up, to their secretary Mr. Elliot, for piers of stone or of wood, with the necessary specifications, and explanations, against the 29th September following.

At this time, several plans and models were offered, and the 19th October appointed for taking the plans into consideration: and also the secretary was ordered to invite engineers, or gentlemen acquainted with engineering, to assist the trustees upon that occasion. Accordingly, upon the 19th several persons attended under that description, and were desired to appoint a meeting among themselves to consider the several plans, and give their opinion to the trustees; and the secretary was ordered to invite the gentlemen who should attend to dinner, at the expense of the trust.

On the 26th of October the engineers delivered their report, which was subscribed by Benjamin Robins, Thomas Innes, J. Leake, John Muller, and John Turner. The most material things that occurred therein were:

That it was improper to lay the foundation of the piers below low water mark, with loose stones thrown in at random.

That if the piers were not carried out into a greater depth of water than $6\frac{1}{2}$ feet, at low water of spring tides, it did not appear necessary to be at the expence of carrying on the foundation by caissons.

That the properest method of laying the foundation of the intended piers in the parts covered at low water, was by making a basement of stone somewhat higher than low water mark, after the manner proposed by Mr. Turner.

At a subsequent meeting, Mr. Desmaretz, Mr. Prat, and Mr. Mill, gave their opinions relative to the manner and materials necessary for the building the piers of the intended harbour.

The trustees then ordered notice of a meeting upon the 15th December, for taking into their consideration all the plans and proposals that had been or should be laid before them, and to come to a determination thereon: and that all persons having any thing further to offer, should be desired to deliver in their proposals before that time; recommending a full meeting of the trustees on this extraordinary occasion.

At this meeting several plans and sections were examined, amongst which was a plan from Captain Robert Brooke of Margate, and a section from Mr. Desmaretz chief engineer at Portsmouth; and at a subsequent meeting, three more plans and sections were delivered, amongst which was a plan and section by William Ockenden Esquire, one of the trustees: and at a meeting after that, ten different plans, laid before the board in consequence of the original advertisement, were examined; and an abstract ordered to be made by the secretary, and laid before the next meeting; at which, on the 12th January 1749-50, it was resolved, that the harbour should be proceeded with according to the plan signed by the chairman, subject to the further alterations of the board. That the east pier should be proceeded upon with stone; and the west pier with wood.

At a subsequent meeting it was resolved, that the plan and section proposed and delivered by William Ockenden Esquire, for erecting a stone pier, should be the method of building the east pier; and that the section and model which was proposed and delivered for a wooden pier by Captain Robert Brooke, should be the method of building the west pier to low water mark neap tides: and that Mr. Ockenden and Captain Brooke should be applied to, for their description of the proper materials for the piers respectively proposed by them.

The

The 2d February 1749-50, it was resolved, that the east pier should be carried on by workmen appointed by the trust, and materials purchased for 100 feet of pier; and Thomas Preston was appointed mason or foreman of the stone work; who by the Board's order, set out for Maidstone, Folkestone, Dover, and Ramsgate; and was to follow the instructions given him; and Captains Conway, Stevens, and Bennet, were desired to assist Captain Brooke in purchasing materials and carrying on the west head.

Mr. Preston's first report of the 23d following, chiefly contained an account of the stone materials afforded, and used at the places specified; whereupon he was ordered to go to Purbeck, to make the proper enquiries concerning the stone there: Mr. Ockenden, Sir Peter Thompson, Mr. Fry, Captain Boscawen, Captain Hughes, Mr. Hyde, Mr. Norris, and Mr. Pole, were appointed a committee for carrying on the east head, and were desired to confer with the committee for the west head, as often as they should find necessary. Mr. John Scott was appointed foreman for carrying on the west pier.

Things being thus settled, nothing happened but what might be expected to be the result of the dispositions mentioned; and it is worthy of notice, that a quantity of Barrow limestone was got, as recommended by Mr. Preston.

In 1751, a committee being appointed by the board to make a survey of the state of the works, made their report the 25th July. The most material things to be observed were as follows:—

That the stone pier extended 390 feet, of which 104 feet were completely ready for the parapet, and the rest above the reach of a spring tide; and that while the committee was there, the foundation was run on 83 feet further, in the whole 473 feet. They examined the work, and found it free from any kind of failure whatever.

The west head was carried out about 460 feet from the cliff; and 540 feet thereof were proposed to be completed that year.

The committee were attended by Mr. Turner of Gosport and Mr. Vincent of Scarborough, and recommended the use of ashler instead of backing stone, since a cube foot of shell lime cost more than a cube foot of ashler.

A locker or grind was then recommended, the committee being of opinion it would collect the sand and shingle in the outward angle of the east pier with the land.

* At this time shell lime was used for the backing of Ramsgate harbour.

By.

By the separate report of the engineers, of the same date with that of the committee, it appears they were of opinion, that the part of the stone pier then done, was but barely sufficient to resist the force of the sea; therefore recommended the future parts to be made with 40 feet base, and 30 feet at top; and an additional course of ashler, to the height of 18 feet above the foundation, both inside and outside; and above that, one course only; the core to be lessened. The chalk to be well beaten, and mixed with grayel, and not mixed with mortar as then practised. All the ashler to be set with terras mortar, and the backing mortar made with brick-duft or sea-coal ashes.

In surveying, they found the bottom regular, and in the circumference of the harbour, the depth of low water not exceeding five feet six inches; and that the foundation might be carried out without caissons, so as to answer the design, in a manner by them described; which was that of laying large Portland blocks in the ground courses, so as to reach above low water.

The following Board agreed to the use of ashler for backing, for the reasons given by the committee in their report. A locker or grind to be made as proposed. Captain William Read was appointed haven-master, with instructions to hoist a flag when there was ten feet water at the old pier head.

6th December 1751, a general meeting was appointed to consider of the method of founding the piers beyond low water mark, when Mr. William Etheridge produced a model of a caisson; and a model of a tool, and method of working it, for making a trench, and levelling the ground under water for setting the caisson upon. Captain Robert Brooke sent a model for laying the foundations of stone, without caissons, accompanied with a description. In consequence of which the trustees ordered an advertisement for contractors to deliver plans, proposals, and estimates, for constructing the piers beyond low water mark.

The 3d January 1752, Mr. James Morehouse presented a plan, proposals, and estimates; which however were not approved; but it was resolved, that a foundation, not exceeding 200 feet, should be carried on with large blocks of stone, agreeably to two plans given in by Mr. Preston the mason.

24th January; it was resolved that the said 200 feet of stone pier should have its foundation laid in a channel or trench, dug into the chalk ten or twelve inches deep; and a motion was made, and agreed to, that a surveyor should be appointed; and that a proper advertisement

advertisement should be considered for the purpose: Friday the 21st was appointed for the election of one, from such persons as should offer, to inspect and direct the careful and expeditious carrying on of the building; and the mason's report was postponed till a surveyor should be chosen; but Boulogne lime and lime kilns were ordered to be set about immediately.

21st January. It was resolved that such surveyor as should be chosen, should have a salary of £200. per annum, and reside at Ramsgate.

On this occasion, seven persons applied; amongst whom were Mr. Etheridge, and Mr. Vincent the Engineer of Scarborough Pier, who both produced ample testimonials; but on holding up of the hands, the major was declared for Mr. Etheridge, who was strongly recommended by Mr. Ockender, and who received on this occasion the thanks of the Board for his plan, care, and attention; and which were desired to be continued.

28th February. Instructions were given by the trustees to the surveyor, and were in substance as follows:—

— The surveyor is to reside in Ramsgate, and not be absent without leave first obtained from the trustees at one of their meetings; and to have the inspecting and directing of all the works that have already or shall be hereafter carried on, under the direction of the trustees of Ramsgate Harbour; and also to have the direction of all the persons employed therein, at Ramsgate, except the clerk of the cheque. He is weekly to transmit to the secretary an account of the progress of the work, and of the transactions relative thereto, that they may be laid before the Board at their several meetings. He is truly and faithfully to inspect the several materials which shall be delivered, and report to the Board those which are not according to agreement or contract; and frequently to examine the list of the workmen employed, and see that they perform the labour they are paid for; and as soon as he conveniently can, he is to take an account of the abilities of the several workmen employed, and report to the secretary, whether they are deserving the wages therein charged; but no alteration of wages shall at any time be made by him, without first mentioning his intention to the trustees, and receiving their approbation. The increasing or lessening the number of workmen to be left to his discretion. But he is from time to time to acquaint the Board of his reasons for whatever alterations he shall make among them. Nor is he to make any material alteration of any kind, without previously acquainting the secretary thereof, and taking the directions of the trustees thereon. In general he is to inspect and direct every thing relating to the works, so that they may be carried on in the most expeditious and frugal manner."

25th March. Mr. Etheridge delivered his first report, which describes the state of the works at Ramsgate on a general view; and having inspected a cargo of backing stone brought from Purbeck, he thought it very good, and capable of making very sufficient work, without building the wall entirely with ashler; but for the benefit of the work, he recommended to send a proper person to Purbeck, at the expense of the trust, to see that the stone be good, properly worked, and the courses shipped as wanted; which was afterwards ordered by the Board.

Here it may be necessary to observe, that Mr. Etheridge appears to have been a person of a truly mechanic genius, and having been brought forward by the celebrated Mr. King, carpenter of the works of Westminster Bridge, as his foreman, and after Mr. King's death become his successor in completing this branch of those works, might be presumed to be a man of much experience in the carpentry line: * but being here appointed director of the whole work, and looking upon himself as competent to the masonry as to the carpentry branch, there very soon arose a difference of opinion betwixt the surveyor and Mr. Preston the mason, that afterwards turned out of great detriment to these works. Mr. Preston, though by no means equal to Mr. Etheridge in general mechanical knowledge, yet was an excellent mason, and well informed in the nature of the materials proper to his trade:—the making of mortar being rather of a chemical than a mechanical nature. Mr. Preston, before the appointment of Mr. Etheridge, not being satisfied with the use of shell lime under water, which was in part used at Ramsgate Harbour, recommended to the trustees the trial of various lime stones; viz. Aberthaw, Barrow, and that of Boulogne, of which cargoes had been ordered; but their merits had not then been sufficiently investigated. Mr. Etheridge unfortunately had adopted shell lime for waterworks, and accounted that of Maidstone, and St. Vincent's Rocks at Bristol Hot Wells, as preferable to the above. †

Mr. Etheridge, as reported, being of an austere temper, not readily giving up what he had once advanced, a shyness took place between these two officers; which though it did not prevent either of them from punctually doing his duty, that is, did not prevent Mr. Preston from scrupulously pursuing his orders from Mr. Etheridge; yet it prevented that interchange of sentiments and confidence, which is so essentially necessary among the principal officers of a great work or enterprize, that it may be carried on to the best advantage.

* Mr. Etheridge afterwards designed and built the famous wooden bridge at Walton-upon-Thames; the middle arch of which spanned 120 feet.

† See the chapter of water cements, Smeaton's account of Edystone lighthouse.

Mr. Etheridge now proceeded to put in practice his proposed method of laying the foundation of the piers, in cales or caissons, and shewed that method of digging a trench under water, and levelling it, which, being attended with certainty, and every necessary degree of dispatch, has ever since been the method put in practice here, and so continues to this day.

Every thing appeared to go successfully on during the year 1752; and the committee of the 29th September, reported that 68 feet of stone pier, of the same dimensions as the east pier, had been added to the 550 feet of timber work of the west pier, and 138 feet of foundation carried out five feet high.

The 26th January 1753, produced an order of Board, that Mr. Ockenden, and any other gentlemen of the trust, should be desired to go to Ramsgate to consult with the surveyor there, and give directions for a proper plan to be drawn of the extent and manner in which the work should be carried on and finished; and that the said plan should be laid before the Board for approbation.

14th May 1753, the Board read Mr. Ockenden's report of his survey made at Ramsgate, and considered the plan for carrying out the work, which is dated the 21st April, and signed by him and the surveyor, but came to no resolution thereon; however Mr. Ockenden received the thanks of the Board, for his great care and pains in making his late survey and report.

At a general meeting, 14th December 1753, for considering the plan of the Harbour, a motion was made, that the Harbour be contracted to 1,200 feet in width, according to the plan this day laid before the Board by Mr. Ockenden; which, being debated, was carried on a division of 28 to 15. And on an adjournment to that day se'nnight, the resolution was confirmed; 26 to 7.

Upon this contracted plan, which appears to have originated with Mr. Ockenden, Mr. Etheridge seems not only to have vigorously proceeded, but even to have pushed the execution; for, by the Committee's report on their visitation, the 9th October 1754, after declaring their opinion, that the contraction ordered by the Board would leave the Harbour large enough to contain more ships than would ever have occasion to lie there, at the same time; and "that the curve at the west pier continuing the same as it was in the original plan, would give sufficient room for ships to bring up;" they reported, that at the west pier, the 138 feet of foundation mentioned last year to be laid, was taken up, and a tempo-

rary cross wall of backing stone had been carried out eastward 278 feet; but that from the east end of this, nearly 300 feet had been carried out southerly, to five feet high and upwards; and 111 feet to 19 feet 8 inches; and furthermore, that the piles had been driven for founding 80 feet more.

At this meeting the surveyor pointed out a communication to be necessary by land to the west pier at high water, and recommended a stair-case from the top to the bottom of the cliff; which work being soon after executed, was called Jacob's Ladder, which name it still retains.

This appears to be the last work of Mr. Etheridge at Ramsgate, for while the works of this summer were going on, remonstrances from the trustees came from several ports, declaring strongly against the contraction, and which ended in an application to Parliament in 1755; when the petition of merchants, owners, and masters of ships, whose names were subscribed, set forth; "That from the works carried on under the direction of the Trustees of Ramsgate Harbour, for some time the petitioners had great reason to hope, that a safe and commodious Harbour would be made there, for the reception of ships and vessels; and thereby the intention of the Legislature answered in imposing the duties; but that, in or about December 1753, the said Trustees had resolved to alter and contract the said Harbour; and during the last summer, such works had been carried on towards altering and contracting the same, that if further proceeded in, and finished according to the said resolution of the said trustees, would, in the petitioners' apprehension, render the said Harbour in a great measure useless; and that the expense thereof would be lost to the public."

"That as the petitioners were fully convinced a safe, commodious, and useful Harbour might be made at Ramsgate, to the great advantage of the commerce of this kingdom, under skilful and proper directions;

"The petitioners therefore humbly prayed the honourable House to take into their consideration this matter, in which the public was so greatly interested, and grant such relief therein, as to the honourable House should seem meet."

The matter of the above petition having been fully heard by the House of Commons, in the early part of the year 1755, that House thought proper to address his Majesty, "that he would be graciously pleased to appoint proper and skilful persons, to make a survey of the works carrying on at Ramsgate Harbour, and give their opinions thereon; and what might be the most proper plan for finishing and completing the said Harbour; to make

an

an estimate of the expense thereof; and that his Majesty would be graciously pleased to cause such plan or plans and estimate, together with an account of all the proceedings of the said persons, to be laid before the said House in the next session of Parliament."

In consequence, Sir Piercy Brett and Captain Desmaretz were appointed to this service; who, the latter end of the same year, delivered their plan, report, and estimate; and in the session of 1756, a bill was brought into Parliament, which was much agitated, and canvassed; but it did not ultimately pass into an act. These proceedings however had the effect of putting a total stop to the works at Ramsgate.

SECTION III.

OCCURRENCES from the stoppage of the works in 1755, to their recommencement in 1761.

IT may in this place be proper to give a short account of this scheme of the surveyors appointed, as nothing was in reality done upon it.

The report of Sir Piercy Brett and Captain Desmaretz is addressed to the Lords of the Admiralty, and was printed in 1756. It almost sets out with saying, that "according to the best of their judgement the works already made, and every plan hitherto imposed, seem liable to very material objections;" they go on to say, "and we think it proper that the work done upon the contracted plan should be taken up, and the materials made use of in carrying out the West Pier."

It is however to be noted, that the whole of the work that had been done, exclusive of what concerned the contraction, was proposed to make a part of their own scheme, being no other than the straight walls or piers from the shore; but they proposed, by engrafting upon them, to carry out the pier heads further by full 400 feet to seaward, than according to any of the plans that had been before exhibited, and which they supposed would place them in eight feet water. They also proposed to make the opening of the Harbour's mouth right towards the Downs; whereas according to the advice of the eleven Captains, mentioned before, all former plans had exhibited that opening to be S. S. W. that is, about three points more westerly than the situation recommended by those gentlemen. The width of their opening, as shewn in their plan, is 275 feet; which is 75 feet greater width than any of the former schemes.

They further proposed, "for the better preservation of such ships and vessels which are sharp built, and liable to receive damage by laying a-ground, to have a basin at the east side of the Harbour, to be sunk sixteen feet from the low water of a spring tide, and partly inclosed with a stone wall, as described in the plan; where 50 or 60 ships of 300 tons might always lie afloat in smooth water: and they humbly conceived, that without such a basin the Harbour would not answer the good purposes intended by Parliament."

	£.	s.	d.
Estimate for finishing the Harbour, according to the plan	153,548	18	10
Add for completing the proposed basin	50,567	14	0
Total expense of the works proposed	£. 204,116	12	10

N. B. From the above the surveyors deduct for old materials to be drawn from the contracted walls, the sum of £.8,210 5s. 4d. so that the total, at the foot of their estimate, stands £.195,906. 7s. 6d.

Such was the plan or scheme of Sir Piercy Brett and Captain Desmaretz, upon which I shall have a few strictures to offer when they come in course.

How it happened that this contracted plan of Mr. Ockenden's, which was productive of so much mischief and delay, came to be so strenuously espoused by him, is not now easy to say; certain it is, that on a calm review it amounted to no more than to make a less Harbour at a greater expense than a larger; and that without any apparent inducement, unless what is alledged in the Committee's last report, p. 89. is to be looked upon as such; viz. that the contraction will leave the Harbour large enough to contain more ships than will ever have occasion to lie there at the same time. How it happened that Mr. Etheridge should come into the scheme is equally wonderful, as Mr. Etheridge appears to have been a very ingenious person, and which therefore can scarcely be accounted for, but from jealousy between him and Mr. Preston, who it seems was against the contraction. Finally; how it came to be adopted by the trustees at large, many of whom were able and experienced seamen, can only be accounted for by supposing Mr. Ockenden, having had occasion to consider works of civil engineering in his private affairs, became the leader of the majority; but still, why Mr. Ockenden, who was a man of fortune, and then was, or had been in Parliament, and does not appear to have had any immediate interest in this business, should have wished in that strenuous manner to lead the trustees into a scheme so unnecessary, is to me at this day equally wonderful and unaccountable;

countable; but in this I am firmly persuaded in my own mind, that had Mr. Etheridge suffered Mr. Preston to have had his due weight, this scheme of contraction had never been brought forward; which would have saved the trustees much trouble, the trust much expense, and the work itself great loss of time.

In this state the Harbour was at the time of this struggle, the east pier being carried out 757 feet from the shore, and the west 849. There however appears not the least apprehension from the public that the situation of the Harbour at Ramsgate was improperly chosen; the effort was, that it should not be contracted, and its utility thereby diminished; nor did any seem to wish it enlarged, Sir P. Brett and Captain Desmaretz excepted; and how must these gentlemen have stood aghast, surveying their projected basin (sixteen feet under low water mark) could have been at all executed, if they had afterwards found, on turning the curves of the piers, that the operation of nature was to fill it up, not only level with, but much above the level of the ground wherein it was dug.

After this total stoppage of the works, a considerable pause followed; for we do not find the record of any transaction, till 30th April 1760, when the Board came to a resolution to proceed with the works, and gave an order for stone and other materials necessary for the purpose. It may indeed seem extraordinary, that in the last four years nothing was done. But I have been informed that the trustees were totally at a loss what to do, as the works had been entirely suspended, and no new act of Parliament made to chalk out what was to be done. In this interim, I understand, the trustees applied to the House of Commons, and also to the Lords, and were told verbally, that as nothing had been done to suspend or alter their original powers, the best way would be to proceed according to their best discretion. Accordingly the 20th June 1761, a Committee, by appointment of the Board, assembled at Ramsgate, and reported that it would in the first place be necessary to take up the contracting walls; of which they ordered a beginning.

SECTION IV.

TRANSACTIONS of the Trustees from the recommencement of the work in 1761, to the end of the year 1773; when the Committee pressed the Board to consider of more effectual means for cleansing the Harbour.

A COMMITTEE, by appointment of the Board, met at Ramsgate the 25th June 1762, and reported that a good deal had been done in laying fresh foundations, and taking up the works.

works of the contraction. Little had been then done at the east head ; and they recommended the works to be for the present carried on at the west head only *.

The several successive committees of visitation chiefly contented themselves with reporting the progress of the work. That of August the 25th 1766, particularly mentions that the work of the fourth kant or flexure of the east pier towards the west, was then going on, and the second kant of the west pier was in hand. "That the Committee observed a collection of sand in the harbour, increasing under the east head, near the stairs ; and recommended, as the principal work for the next year, to finish the west head as soon as possible ; which they hoped would prevent a further increase."

Till this visitation, the works of Ramsgate Harbour (the stoppage from the contracted plan excepted) appear to have gone on with alacrity, and in full confidence of every degree of success that had been expected ; but it was now a mortifying sight to the trustees to find, that no sooner had they begun to bend the walls towards one another, so as to afford protection as a harbour for shipping, than sand began to collect, threatening to choak it up. This struck the trustees with so much chagrin, that the year 1767 had no visitation ; and in July 1768, after reporting the progress of the walling, they only recommended the work to be continued at the west head, without mentioning the state of the sand †.

The successive accounts from Ramsgate contained so little of consolation, or hopes of amendment, that the years 1769 and 1770 passed without a visitation from the trustees ; but the next year the Committee's Report, which bears date Ramsgate, 25th August 1771, after stating the progress, and that the east head was founded, acquaints us, that the Committee, in order to fix the entrance of the harbour, directed three poles with flags upon them, to be erected one at 200 feet, one at 250, and the third at 300 feet from the east head, which last was then found to be twenty-five feet distance from the work of the west pier ; and that the Committee, after taking several different views of the harbour, and upon mature consideration, recommended that the entrance be 300 feet ; and Mr. Preston was then directed to prepare a proper finishing for the west head, agreeable to those dimensions.

* In this report mention is made of a contract for getting stone upon the sea shore under the cliffs at Lyme Regis in Dorsetshire, for burning into lime. For the qualities of this lime, see Smeaton's account of Edystone.

† The most striking incident of this report was, that a vessel with lime-stone from Lyme had run foul upon the works, and done them considerable damage, which shews this lime to have been in use at Ramsgate.

The Committee conclude their Report with observing, that though a hopper and two lighters had been employed since January 1770 to empty the harbour, yet they were sorry to inform the trustees, that the sand had much increased therein ; but that they had given directions to continue, with the utmost diligence, to do every thing in their power to make the harbour useful ; and recommended to the Board to consider if they could find out a more effectual method.

The Committee's Report of 1772, comprehends only the report of progress ; the two heads being now in great forwardness.

Ramsgate, 31st August 1773, the Committee, after reporting progress towards finishing the heads, and that an engine had been added to a lighter for taking up sand, and another Engine for throwing up sand had been repaired, add that they could not help expressing their great concern in finding a vast quantity of sand and fullage lodged in the harbour, notwithstanding that since January 1770 upwards of 52,000 tons had been taken out at an expense of £1,100, and it was feared it was rather increased than diminished ; and furthermore that the men employed herein refused to work without an increase of price.

The Committee desired to remind the Board that in 1771, the gentlemen expressed their apprehensions on the same account ; and recommended it to the Board to consider of some more effectual method of clearing the harbour ; that in consequence thereof the Secretary had directions to write to Mr. Smeaton, that the trustees would be glad to have his advice upon the clearing and deepening of the harbour ; but as the Committee were informed that he could not attend them that year, on account of a pre-engagement of his to go to Ireland, the Committee therefore advise nothing more to be done, till the opinion of that gentleman, or some other able engineer, could be had. The Committee however observe, that of the sand thrown over the east pier, considerable part returns with the tide, and settles in the harbour : therefore should the Board think it advisable to continue taking up the sand, &c. they recommend it to be taken 200 feet from the east head, and 400 feet range along that side ; and that it be carried up in the harbour within the 119 feet of cross wall now building ; and to prevent its washing out again to build another wall joining that, right in towards the cliff.

SECTION V.

PROCEEDINGS of the Trustees from the beginning of the Year 1774 to the delivery of Mr. SMEATON's Report, and Transactions upon it, to the end of the Year 1778.

RAMSGATE, 6th April 1774, Mr. Smeaton attended a committee of nine trustees and the secretary.

The storekeeper and harbour-master were ordered to prepare an account of all the sand and fullage that had been carried out of the harbour, for the information of Mr. Smeaton. The harbour-master, foreman mason, and boatmen to attend him, in taking soundings, &c. In consequence of which he proceeded to make experiments upon the quantity and nature of the silt brought in, and to investigate every matter that appeared to him necessary to make a full report upon the subject of cleansing the harbour now before him.

The Committee further report that Mr. Preston laid before them a plan for cleansing the harbour, by harrowing up the sand, so that it might mix with the water, and be carried out with the ebb tide; and he was ordered to prepare a model of the machine for that purpose, as soon as possible, and send it for the inspection of the Board.

The 27th August the same year, the Committee again met at Ramsgate, and mention that a quantity of stone had been laid to secure the outer end of the east head; and that 260 tons of Portland had been taken out of the foundation of the contracted wall.

Mr. Preston now produced a model for cleansing the Harbour; in consequence, the Committee gave directions for making a number of rakes for stirring up the sand in the Harbour; and the 29th the Committee stationed fourteen men with the new rakes at the west side of the Harbour, at two-third ebb, and attended their working till flood; and ordered them to continue working every tide for seven or eight days; and that stakes properly marked should be driven where they worked, and a marked staff to be got by the harbour master, to take the depth of the sand at the centre, within and without the Harbour's mouth, to ascertain the effect of the rakes in reducing the fullage of the Harbour.

24th October, Mr. Smeaton transmitted his report on Ramsgate Harbour, in consequence of his survey of the 6th April before mentioned; an abstract and extracts of the most material parts thereof, are as follows:—

“ Having

“ Having been consulted by the trustees of the Harbour of Ramsgate, upon the best and most effectual method of clearing the harbour from silt gathered therein, having carefully viewed the said harbour in April last, in the presence of a Committee of trustees, and having taken such soundings, admeasurements, and other observations as appeared necessary; having also considered the several plans and papers since put into my hands, by the Board, it appears to me as follows:—

“ That a large mass of silt, consisting partly of mud but chiefly of very fine sand, has been brought into the harbour by the tide, the tide water upon this part of the coast being charged with a considerable quantity of mud and sandy matter, whenever it is agitated by the wind, accompanied with a quick flowing tide. This silty matter being thus carried into the harbour along with the water that contains it, and there finding a place of repose, settles to the bottom; and as there is nothing to raise the mud upon the reflow, the water quietly ebbs out of the harbour, leaving the silt behind. And as the same causes constantly operate to produce the same effects, a continual increase of silt must be expected to take place, till some cause is brought to operate in a contrary way.

“ This is the natural tendency of all harbours; for wherever there is mud or matter to deposit, an addition to the soil is the natural consequence of a place of repose; and a deposition and increase must take place, unless there are powers either natural or artificial to produce a contrary effect.”—“ The common natural power is a fresh water river, which continually tending towards the sea, and often, in time of floods, with great impetuosity, makes an effort to carry out whatever opposes it. The sand and silt therefore brought in by the tides, is carried out by the torrent of fresh water. Harbours therefore that have no land water or back-water cannot naturally keep open for a large course of years*. These being the effects of the powers of nature, we must by no means wonder that the harbour of Ramsgate, into which and through which not the least rivulet or runner of fresh water takes its course, has obeyed this general tendency. For, in proportion as the work of the piers has advanced, the space being inclosed, and the water rendered more quiet, and in that respect more fit for the purposes of a harbour, in much about the same proportion has the silting taken place, and must continue to increase till the area of the harbour becomes dry land, and instead of a receptacle for ships, exhibits a field of corn; that is, unless recourse be had to such artificial means as have the due efficacy.

“ How far these effects were, or might have been, foreseen before the harbour was built; or being foreseen, how far it might have been proper to build a harbour there, is

* Large natural harbours or arms of the sea will necessarily be a long time in filling.

not now the question. The fact is, that a noble piece of masonry has been erected, at a very considerable expense, inclosing a large area in a place where a harbour must doubtless be of very great utility; in case the ground so inclosed remained as clear of silt as it was before its inclosure. The question therefore now is, what in effect you put to me; how to make it as useful as possible, and at the most moderate expense?"

In the course of this report, it is stated from actual computation, that at this time there was not less than 268,700 cube yards of silt in the harbour: that the two barges then employed by the trustees, with ten men each, got about seventy ton of silt per day: and supposing them capable, from weather, regularly to work at this rate, which is scarcely possible, and that a ton of silt will be a cube yard; of which, in reality, it is much short; yet the harbour at this rate would be above twelve years in clearing, even supposing that no fresh silt were to come in during the time.

It is further shewn, that the whole harbour contains forty-six acres; and that the area of the external harbour where the silt chiefly lies, being thirty acres and a half, one tenth of an inch in thickness over this whole area, would amount to 410 cube yards, or tons; and this at seventy tons per day, would take a week to clear. Now supposing the mud to have come in at this rate only, the present mass, independently of what had been carried out, would have taken twelve years and a half to collect: but as it has been chiefly collected since the inclosure of the harbour, by the currents having been got above half tide*; the increase of silt could not be reckoned at less than double that quantity, or one fifth of an inch per week; which would afford a continual employ for four barges; and therefore that this, with the clearance of the present accumulation, and that their work must in reality fall short of the calculation, would render the whole so tedious a business, that it by no means appears to be the cheapest, or most effectual means of clearing the harbour; which was the question before Mr. Smeaton. He therefore proposed, "a method of procuring an artificial backwater by means of sluices."

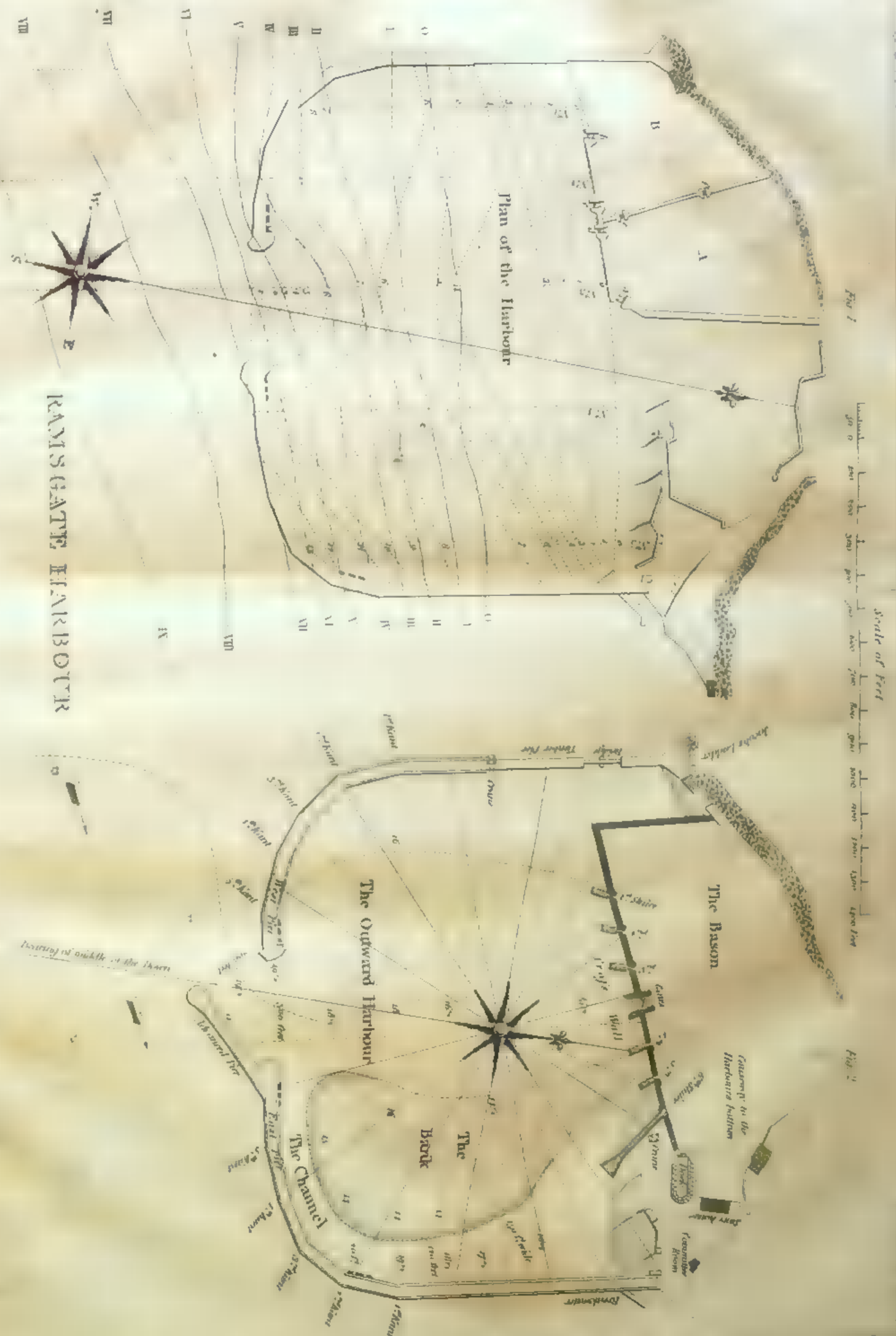
"Where no fresh water is to be procured, as is the case at Ramsgate harbour, the only resource is to construct a pool or basin to take in the sea water; the tide having there a considerable rise and fall. This has been done in many cases abroad, and particularly in the low countries, and in some cases in England; but the method has fallen into disrepute here, by its having been found, that the basin into which the tide water has

* It was only at the visitation of August 1766, that the growing of the sand was first noticed by the trustees.

been

Published as the Act directs, by Longman, Street, Port, and Down, Waterman, Row, London.

STATE of the HARBOUR in 1774.
with a Design for a Double Basin & Sluices
for Scouring out the Silt. by J. SMEATON.



STATE of the HARBOUR in 1790.
with the Principal Works then Executed.

been received, has itself in a moderate space of time filled up and become useless.— A method however suggests itself to my mind, though I do not remember to have any where seen it put in practice, of keeping the bason equally as clear as the harbour intended to be cleaned thereby; and that is by dividing the bason into two parts, by a partition, with a sluice, or sluices, capable of retaining the water in either while the other is empty; for by this means they can reciprocally be made a bason for clearing each other; and be both united for clearing the harbour.”

The harbour of Ramsgate is very well adapted for the execution of this scheme. It has every where a sound bottom of chalk, upon a regular decline from the cliffs towards the harbour's mouth, and from thence out to sea. The set of the tide, which is pretty brisk at particular times, runs crossways upon the harbour's mouth, so that as soon as the sand is washed to the outside of the heads by the artificial current, the natural current of the tides will wash it away, and effectually prevent any bar from being formed before it.

“ The sand itself is of such a nature as to give the least resistance possible to a smart current; for the grains being small, though hard, and specifically heavy, yet not being united by any loamy or tenacious matter, will give way to the impression of a current.”

This report was accompanied with a plan, (see Plate 7. Fig. 1.) distinctly shewing the mode of executing the scheme; which was by carrying forward the cross wall, already begun for another purpose, in an eastern direction to a certain point.

A space thus marked out was shewn to contain eight acres of water; which was proposed to be divided into two basons of four acres each; which it was shewn would produce a very powerful effect in cleansing the harbour, inasmuch as in six months to be likely to make from fifteen to sixteen feet water, at a common neap; and from eighteen to nineteen feet at common spring tides.

Those basons were designed to have nine draw-gates, four upon the westernmost, and five upon the easternmost bason; the whole being pointed in three different directions; two towards the curve of the western pier; four towards the harbour's mouth, and three towards the curve of the eastern pier.

To give the sluices all the effect possible, it was proposed to construct a caisson, shaped something like the pier of a bridge; which being floated to its place, and there sunk, after being

being put in a proper direction, might be used to divert the current to the right hand or left, as might be wanted. This report concludes with observing, that after the silt is carried by the sluices without the harbour's mouth, there is not any danger of its lodging there; because, having particularly examined the outside, and found all clean of sand, there is no doubt but that the same cause that now operates to keep that ground clean, will continue to do so. Furthermore, that the same means that will clear the harbour, will keep it clear: and that it might be expected that the playing of the sluices eight tides at each spring tide will preserve it.

This report, transmitted to the Board in October 1774, lay before them till August 1775, when the committee at Ramsgate took into consideration Mr. Smeaton's plan, for making the upper part of the harbour into a basin or basins, for scouring the harbour by means of sluices. The committee likewise conferred with Mr. Preston, and considered a plan of his for cleansing the harbour, by making all the upper part into a basin, for scouring it with sluices; and Mr. Preston now declared his opinion that it would clear away the silt to low water mark, wherever the power of the sluices could reach*.

After further consideration of the matter before the Committee, they being cautious in adopting a scheme of expense, gave directions in order to try an experiment what effect an artificial back water might have, for a lighter of fifty tons to be scuttled, seventeen inches deep, and fourteen inches broad on the starboard bow; this to be placed near the end of the cross wall, and filled with water. The sluice being opened at low water, it ran out in a few minutes, and made a cavity in the sand of several feet in diameter and depth. But the ground here being higher before the head of the lighter than at its stern, the water spread a stern, without making the impression expected.

The Committee now ordered the lighter to be removed, and placed between the cross wall and the harbour's mouth; and there repeated the experiment. The first tide the water being let out, made a greater impression than before; but yet spread itself without making any channel.

A channel was then ordered to be made and guarded with planks, and in the afternoon (the lighter remaining in the same place) the experiment was tried again; and the cavity

* Mr. Preston seems here to have lost sight of his scheme for harrowing up the silt, proposed to the Board in April 1774; and which was tried by the Committee in August following: in short, ten months after the delivery of Mr. Smeaton's report, Mr. Preston seems to have come to a different view of this business to what he had before.

made by the discharge of the sluice, was about seven feet wide at the surface of the sand, and six feet deep to the bed of the chalk; and a channel was then forced of near 100 feet long. The Committee now seeing the effect of the confinement of the water, and of repeated discharges, tried the experiment of the barge twice more, when the hole was rendered ten feet upon the surface of the sand, six feet deep to the chalk, and three feet wide upon the bed of chalk; the channel being full 100 feet long; and the stream carried some clouds of sand to a considerable distance. These experiments were tried in the presence of Messrs. Barker, Slater, Aubert, Laprimaudaye, Bennet and Bennet junior, who all became fully satisfied of the effect to be expected from sluices when made in large.

Mr. Barker and the two last mentioned gentlemen continuing at Ramsgate another week, in that time further consulted with Mr. Preston, upon the eligibility of carrying the wall already begun, across the harbour to the old pier; in order to make all the upper part of the harbour into a basin for scouring it with sluices: and after conferring with several old men of the town, respecting the most practicable method of clearing the harbour, Mr. Preston was ordered to prepare estimates of the stone and timber for the cross wall and sluices, and Mr. Stead the carpenter, to prepare an estimate of the expense of making one sluice, and the time necessary to construct it; and to make a model of one, to be sent up to town for the inspection of the Board. The result was, that the Committee finally recommended to the Board, that Mr. Preston's plan for cleansing the harbour by means of sluices should be carried into execution with all possible dispatch.

In the year 1777, Mr. Preston the mason being then dead, Mr. Hurst, who had been foreman under him from the beginning of the work, appears as master mason, and Mr. Henry Cull as his foreman. A considerable progress with the cross wall and sluices, as well as other works of the piers, was reported on this visitation as the produce of this year's work; as also, by the Committee of July 1778, a still further progress in the works of the cross wall; the floor of the fifth sluice being laid; and the great gates, and five sluices framed. The Committee now perceived a greater agitation of the sea within the harbour, than before the cross wall was built so far forward; and recommended a range of piles and planking to be erected on the east side of the harbour to abate that agitation; and be a means of making that part of the harbour, which is the desirable station for the shipping, more safe and quiet. This to be done with all possible dispatch, and the cross wall to be carried out with all expedition.

SECTION VI.

The first Starting and Effects of the Sluices in 1779, with the Account of their Operation, to the end of the Year 1781.

1779.—THE Committee of the 9th August report the range of piles driven, and in-part planked, the works of the cross wall much advanced; Mr. Barker, earnestly desiring to see a trial of these works, though far from finished, or the walls got up to high water, yet, the 1st, 2d, 3d, and 4th sluices being fixed, made a strenuous effort to get the great gates hung, and the fifth sluice made capable of penning in the water while he staid at Ramsgate. Messrs. Aubert and Laprimaudaye at this time arrived, and Mr. Paris attending: the gates being hung, and all the sluices put down at high water, the Committee attended at low water, and having ordered all the men to be ready, and placing them in proper proportions at the gates and sluices; the men applied themselves to the handles to start the sluices, when the spindles upon which the wheels were fixed, broke upon the first attempt of every sluice; so that at present there was no possibility of raising any more than the two sluices in the gates, and which indeed were drawn by tackle blocks; but the force and power of the stream issuing through these two sluices only, was so amazingly great, that in its immediate action it forced up the Chalk Rock to the depth of six and seven feet, and carried pieces of it of three to four hundred weight, to the distance of 60 or 70 feet; and in its course, cleared away the silt and fullage down to the chalk, to low water mark; the stream continuing strong 2 or 300 feet, without the Harbour's mouth. Some defects were found in the wall and other parts, which being remedied as well as time would permit, the water was ordered to be pent up in the basin again; and the tackle blocks to be applied to the sluices, as well as to those of the gates; yet though all the people were properly placed, there was no possibility of raising more than two sluices, exclusive of those of the gates, notwithstanding 30 or 40 men heaved at each sluice. However, with a great deal of labour and difficulty, the Committee afterwards got those sluices started twice again, and were happy to inform the Board, that the effects produced exceeded the general expectation: the stream of water carrying the sand a great way beyond the entrance of the Harbour, in such quantities, that the sea at the distance of a mile and a half, was observed to be exceedingly thick and foul. The deep channels through the sand in the harbour, appeared similar to the beds of rivers; and the general voice seemed unanimous in testifying their firm belief, that the back water would effectually cleanse the harbour.

To

To devise some proper method to start the sluices, seemed a difficulty not easy to be got over, as the people could not contrive any purchase adequate to the purpose. But Mr. Aubert observing that the planking of the sluices were put to draw cross ways of the plank, which operating in a rough groove of stone must necessarily cause a great friction; orders were immediately given for the trial of one made in a different way, and they then began to work with sufficient ease; and the spindles being repaired and made of wrought iron, the water was again pent up, and it was discharged in the presence of the before mentioned gentlemen, and of Mr. Sibley and Mr. Lutkens, who were then arrived, and things were now found much better adapted to do their duty; but the Committee finding that the rapidity of the stream of water issuing from the sluices had, by its great power, forced up the chalk rock to a considerable depth; insomuch that the cross wall would be in great danger of being undermined; they gave orders to the mason and carpenter to construct proper aprons for preventing those effects in future.

The Committee further report, that during the last winter it had been a prevailing complaint that the Harbour had been greatly agitated, and at some particular times rather unsafe for ships to lie in; which was not the case before building the cross wall, as the sea then broke and spent itself upon the shore: and as it had been observed that the sea mostly ranges along the western pier, and that the cross wall stopping and repelling the swell, it returns on account of its not having any vent or outlet, and causes that great disturbance and agitation now complained of. Under these circumstances, the Committee recommended that about 2 or 300 feet of the western end of the cross wall (or what might be necessary) should be taken down; and that from thence a wall should be built up towards the cliff; and furthermore, that about 80 or 100 feet of the timber pier should be taken away, beginning about the end of the cross wall, and the opening to extend towards Jacob's Ladder; the Committee having great hopes that this plan would render the Harbour more safe and quiet.

The Committee further mention it as a general opinion, that another sluice would be found necessary to scour the upper or northern angle of the east pier; and therefore recommended that a sluice should be made from the angle in the old pier, to be carried through the work yard to the end of the carpenter's shop.

It may here be proper, before we go on further, to advert to the state in which the Harbour really was previously to the trial of the sluices: indeed, it was so bad that I do not find any memoranda have been preserved of its condition. I must therefore recur to the state in which I found it at the time of my survey in 1774. At that time, in the very centre of the outward Harbour the sand was accumulated to an elevation four feet above the

the level at which the thresholds of the present gates are laid; and this being then the best, that is the deepest part of the Harbour, vessels drawing above ten feet water could hardly be said to get into it even at spring tides. At low water there was no water to be seen in the Harbour, except a small roundish area reaching a little within the pier heads at neap tides, and at spring tides none but what was immediately between the heads. Under the curve of the east pier, which was the proper birth for large vessels (could they have occupied it), the sand lay considerably higher; so that in the third angle, which is naturally the best birth, there was no less than thirteen feet in depth of silt, lying upon the chalk bottom, which would be seven feet above the level of the present threshold of the gates; and if this was the condition of the Harbour in 1774, we must conjecture how much worse it had become in this year 1779, when the sluices were first brought into action, as has been described, notwithstanding that the barges had been all the time employed in getting the sand out as fast as they could. In this forlorn state the Harbour of Ramsgate had become justly reprobated by the public, as a work not having the least appearance of utility, or likelihood of being made useful.

1780.—The Committee's report dated 7th August, notices that 150 feet of the cross wall had been taken down, and a considerable progress made with the returning wall towards the cliff; and that 100 feet of the timber pier had been removed to make an opening; which was then made and passable by a wooden bridge, with a stone pier in the middle. Aprons being also laid to all the sluices, and examined by Mr. Barker, the water was ordered to be shut in, and Messrs. Slater and James arriving, took their station at the pier head, and found that the stream ran exceedingly strong beyond the mouth of the Harbour, carrying the sand into the tide.

The fifth sluice having not yet been put in action, it was ordered to be forthwith completed; and Mr. Barker finding a great bank of sand extending eastward of the fourth sluice, directed the harbour-master to place two barges to turn the current of the water to run upon the point of the bank. The fifth sluice being completed during Mr. Barker's stay, he ordered it to be run without the rest, and found the effects of it to be amazingly powerful; insomuch that in a few times running it entirely cleared away the fullage within a few feet of the old pier, and carried out of the Harbour's mouth great quantities of sand. Mr. Barker being desirous to have all the sluices completed as soon as possible, and as there was the greatest reason to believe that the fifth, with an addition of a sixth sluice, would operate very powerfully in cleansing the east side of the Harbour, which, as already noticed, is the principal birth for shipping, he ordered the digging for the foundation of the conduit of the sixth sluice to be begun; and before he left Ramsgate, saw a considerable

able length of the foundation dug, and the stone work itself begun. He also left directions to run the sluices once in 24 hours, and ordered the chalk that had been forced up by the running of the sluices, to be laid under the cross-wall to secure its foundation.

Observing now, that a prodigious quantity of silt accumulated in the basin or upper harbour, and that the clearing it would make it vastly more commodious for shipping; by way of experiment he ordered the sluices to be put down at low water, and that one sluice only should be opened about an hour before high water; for it was supposed that the action of the water issuing into the empty basin, would stir up and loosen the silt so as to facilitate its getting out when the sluices acted in the contrary direction. The experiment was twice tried and found to have some effect; but the power of the water seeming to endanger the foundation of the wall, he found it more adviseable to order that six or eight men should attend at the running of the sluices, to shovel down the silt into the current, when the water was sufficiently down to admit thereof.

1781, Committee's report, August 6th.—The work at the fifth and sixth sluice being now completed, a new channel was ordered to be dug through the sand from the sixth sluice, and a couple of barges to be laid, so as to direct the water thereof through the channel. In a few times running, it was found that the bank was considerably decreased, and that the water of this sluice flowed so high as to overtop the conduit wall; from the whole of the operation of the sluices there appeared the greatest reason to believe that the fifth and sixth sluices, and particularly the last, would be effectual in cleansing the east side of the harbour.

From this era Ramsgate Harbour began to put off that forlorn appearance of a repository of mud, and to assume one more respectable than it had done for 15 years before; and the trustees seeing that they were now become competent to the cleansing of the outward harbour, and finding the great utility of the basin, turned their mind towards the clearing of that from the fullage gathered therein; for which various propositions presented themselves; viz. First, the barges to be filled at a price per ton, as had been done in the outward harbour: Secondly, the fullage to be taken up and lead out with carts: Thirdly, a premium of three-pence per load to be offered to the farmers to take it out as manure: Fourthly, the barges to be filled by the labourers, and carried out by day works: Fifthly, the barges to be filled with water, and being scuttled, to play upon the bank of fullage at low water, in the manner the experiment was conducted; labourers being employed to throw down the bank of sand. The two last of which seemed then the most practicable schemes.

* Necessary also for the purpose of a backwater.

the level at which the thresholds of the present gates are laid; and this being then the best, that is the deepest part of the Harbour, vessels drawing above ten feet water could hardly be said to get into it even at spring tides. At low water there was no water to be seen in the Harbour, except a small roundish area reaching a little within the pier heads at neap tides, and at spring tides none but what was immediately between the heads. Under the curve of the east pier, which was the proper birth for large vessels (could they have occupied it), the sand lay considerably higher; so that in the third angle, which is naturally the best birth, there was no less than thirteen feet in depth of silt, lying upon the chalk bottom, which would be seven feet above the level of the present threshold of the gates; and if this was the condition of the Harbour in 1774, we must conjecture how much worse it had become in this year 1779, when the sluices were first brought into action, as has been described, notwithstanding that the barges had been all the time employed in getting the sand out as fast as they could. In this forlorn state the Harbour of Ramsgate had become justly reprobated by the public, as a work not having the least appearance of utility, or likelihood of being made useful.

1780.—The Committee's report dated 7th August, notices that 150 feet of the cross wall had been taken down, and a considerable progress made with the returning wall towards the cliff; and that 100 feet of the timber pier had been removed to make an opening; which was then made and passable by a wooden bridge, with a stone pier in the middle. Aprons being also laid to all the sluices, and examined by Mr. Barker, the water was ordered to be shut in, and Messrs. Slater and James arriving, took their station at the pier head, and found that the stream ran exceedingly strong beyond the mouth of the Harbour, carrying the sand into the tide.

The fifth sluice having not yet been put in action, it was ordered to be forthwith completed; and Mr. Barker finding a great bank of sand extending eastward of the fourth sluice, directed the harbour-master to place two barges to turn the current of the water to run upon the point of the bank. The fifth sluice being completed during Mr. Barker's stay, he ordered it to be run without the rest, and found the effects of it to be amazingly powerful; inasmuch that in a few times running it entirely cleared away the fullage within a few feet of the old pier, and carried out of the Harbour's mouth great quantities of sand. Mr. Barker being desirous to have all the sluices completed as soon as possible, and as there was the greatest reason to believe that the fifth, with an addition of a sixth sluice, would operate very powerfully in cleansing the east side of the Harbour, which, as already noticed, is the principal birth for shipping, he ordered the digging for the foundation of the conduit of the sixth sluice to be begun; and before he left Ramsgate, saw a considerable

able length of the foundation dug, and the stone work itself begun. He also left directions to run the sluices once in 24 hours, and ordered the chalk that had been forced up by the running of the sluices, to be laid under the cross-wall to secure its foundation.

Observing now, that a prodigious quantity of silt accumulated in the basin or upper harbour, and that the clearing it would make it vastly more commodious for shipping; by way of experiment he ordered the sluices to be put down at low water, and that one sluice only should be opened about an hour before high water; for it was supposed that the action of the water issuing into the empty basin, would stir up and loosen the silt so as to facilitate its getting out when the sluices acted in the contrary direction. The experiment was twice tried and found to have some effect; but the power of the water seeming to endanger the foundation of the wall, he found it more advisable to order that six or eight men should attend at the running of the sluices, to shovel down the silt into the current, when the water was sufficiently down to admit thereof.

1781, Committee's report, August 6th.—The work at the fifth and sixth sluice being now completed, a new channel was ordered to be dug through the sand from the sixth sluice, and a couple of barges to be laid, so as to direct the water thereof through the channel. In a few times running, it was found that the bank was considerably decreased, and that the water of this sluice flowed so high as to overtop the conduit wall; from the whole of the operation of the sluices there appeared the greatest reason to believe that the fifth and sixth sluices, and particularly the last, would be effectual in cleansing the east side of the harbour.

From this era Ramsgate Harbour began to put off that forlorn appearance of a repository of mud, and to assume one more respectable than it had done for 15 years before; and the trustees seeing that they were now become competent to the cleansing of the outward harbour, and finding the great utility of the basin, turned their mind towards the clearing of that from the fullage gathered therein; for which various propositions presented themselves; viz. First, the barges to be filled at a price per ton, as had been done in the outward harbour: Secondly, the fullage to be taken up and lead out with carts: Thirdly, a premium of three-pence per load to be offered to the farmers to take it out as manure: Fourthly, the barges to be filled by the labourers, and carried out by day works: Fifthly, the barges to be filled with water, and being scuttled, to play upon the bank of fullage at low water, in the manner the experiment was conducted; labourers being employed to throw down the bank of sand. The two last of which seemed then the most practicable schemes.

* Necessary also for the purpose of a backwater.

SECTION VII.

TRANSACTIONS from the Proposal of a Dock in 1782, to and inclusive of SMEATON's third visit to Ramsgate in the Summer of 1787; with Transactions to the Death of John Barker Esquire, in the Autumn of that Year.

1782, COMMITTEE's report, dated Ramsgate, 5th August.—On this visit had the highest satisfaction in finding the great improvement that had been made in the harbour by means of the sluices, and particularly in the 11th part; and that in the channel under the east pier, there was full nineteen feet water at a spring tide. This improvement was greatly owing to a terrace fence having been made, for turning the water of the fifth sluice to operate along that of the fourth; but which having been carried in an irregular line, so that the water went over it, did not produce all the effect it might have done; and therefore, by way of expedient, he ordered the barges and lighters to be laid along-side the fence, the more effectually to confine the waters and grind a channel. He had also high satisfaction in finding, that by the means proposed last year, a great part of the basin was now cleared of fullage down to the chalk; and that from the gates to the crane there were fourteen feet water at spring tides, and he supposed that at least 80 sail of vessels might be sheltered therein.

He found in the basin a Venetian vessel of 300 tons, that had been hove down, and her keel repaired; and also a Swedish ship of 340 tons measure, that had been unloaded of 1,700 quarters of wheat in the basin, and there undergone a thorough repair; and with pleasure observed that vessels brought in from the Goodwin Sands, made directly for the gates, and sailed into the basin without difficulty. Therefore, taking all these things seriously into consideration, and finding that this harbour was not only a place of shelter for ships in distress, but also for the repair of their damages at sea; two more articles seemed essentially necessary to make the harbour of that complete utility to the public, that now appeared near in prospect; and these were, a storehouse contiguous to the basin, for the reception of the goods that were thus obliged occasionally to be put on shore while the vessels were repaired; and a dock for occasionally taking in a vessel to be thus repaired. These seemed, indeed, matters so important and of such immediate concern, that Mr. Barker desired to have Mr. Aubert's advice, and that he would also bring down with him Mr. Smeaton, to advise with respect to the practicability of the dock, &c.

Messrs. Aubert and Smeaton immediately attended this summons; and all agreed that the storehouse would be of great utility as well as the dock; but that as the latter was

was likely to be a work of expense, it would be proper not to lay more burthen upon the trust, in the whole, than necessary; and therefore that it would be eligible to let an area of ground for a storehouse on lease to private adventurers, under certain restrictions; but that with respect to the dock, it would probably require that care and caution in construction, as not to make it eligible to be trusted to private execution.

In consequence therefore of my orders, I proceeded to inspect the ground, with a view to the building a dry dock for the graving and repairing of vessels; and to inform myself of every circumstance relative thereto, that could in its nature be then known.

On this visit, it was not with a small degree of satisfaction that I was eye-witness to the very great difference that there was in the condition of this harbour, to what it was in the year 1774, when I was last there: and that the hints suggested in my report of that year being carried into execution, had been attended with every prospect of success that could reasonably be expected.

The gates having been shut in, and having seen the operation of the sluices, what seemed to be now most wanting, was an increase of power so as to widen the channel under the east pier. And as I observed that the bringing of the stream of the fifth sluice to act along with the sixth, was but very imperfectly executed, to prevent loss of time I then staked out a curve for the direction of a fence or turnwater; which being temporarily executed with stakes and boards, and found to answer the end, has, with repairs, remained there to this day.

It was then complained, that the gates were much too narrow; but finding them thirty feet clear width, and therefore wide enough for the largest vessels then expected into the basin; I observed, that vessels any thing near that width could never venture to run in under sail. Nor did it appear to me, that those gates had ever been designed with that idea: for I found the entering angles were very little rounded, and the entering walls themselves upon a parallel; so that the least swerving of the vessels, to the right hand or left, would make them strike the stone work, unless in the case of small vessels where there was a good deal of width to spare. To remedy this inconvenience, I recommended to build flue walls, to project forward thirty feet, and in that length to splay out, or widen, five feet each, so that at this new entry the width would be virtually forty feet; and which might be deemed wide enough for securing the entry of vessels of thirty feet. I also noticed, that if the sharp angles of the stone work of the sluices were also properly rounded off, they would give a more full bore of water.

The gates themselves, also, being of too slight a construction, were already got into such bad condition, that I was desired likewise to make a proper design for a new pair of gates*.

I afterwards took an opportunity of viewing the docks at Liverpool, and early in the year 1783 delivered, not only my designs for new gates for the basin, with the flue walls, which were immediately ordered into execution; but also a graving dock with a timber bottom, like those I saw at Liverpool, and which indeed appeared to me absolutely necessary in a situation like Ramsgate. I knew that the natural bottom would be the same as that of the whole harbour, which was universally a chalk; and which, though it had never been pressed by any excavation under low water mark that had been attempted to be kept above water, yet it might be reasonably presumed, that though the foundation was likely to be free from gross springs, yet it would be subject to such transpirations as could not take place in clay or solid stone, and would therefore need a wooden floor; and as in works of this kind it is usual to call upon the designer, in case any thing in the nature of the ground or foundation turned out different from what was originally to be supposed, there could therefore be no necessity to give directions for every possible case and contingency.

1783, Ramsgate, 4th August.—Mr. Barker found that the storehouse recommended had been built; and that the sharp corners of the sluice walls had been rounded off, in order to give more water way; that a new fence of piles and planks had been executed, to unite the waters of the fifth and sixth sluices; that a hill of chalk in the basin had been ploughed up and removed; that the east flue wall of the gates had been carried up to the height and dimensions specified by Mr. Smeaton's plan; and that the west flue wall was in great forwardness, and he found it to be the general opinion, that these walls would greatly facilitate the entrance of ships into the basin; and that the graving dock, already resolved on by the Board, would be very serviceable in the repair of ships damaged at sea, and brought in for that purpose. During Mr. Barker's long stay here at this visitation, the new gates were actually hung, the water shut in, and every thing found to answer; so that, after seeing the sluices run several times, he concluded that they would in every respect fulfil the intended purpose. He expressed himself as particularly happy in acquainting the Board, that the vast accumulated body of silt which formerly choked up the basin, was now entirely cleared away, and that ships from 200 to 400 tons might

* It was afterwards intimated to me, that, as the dry docks of Liverpool were esteemed of the most complete kind for merchants service, the trustees would wish me to take an opportunity of seeing them.

lie in the basin with the greatest ease and safety, and that in a considerable number: and says, "that in the course of last winter and spring, property to a very large amount had been saved, as several large ships with valuable cargoes were brought in and taken care of. The cargo of one large ship only being estimated at £35,000.; and that under Providence, has been the means of preserving many useful lives to their families,

1784, Ramsgate, 11 July.—From Mr. Barker's report upon this visitation it appears, that a new dock being determined upon by the trustees to be built according to Mr. Smeaton's plan, it was immediately begun; and Mr. Barker laid the first stone 31st July, and the workmen were directed to proceed with all possible expedition*.

On this visitation, Mr. Hurst the mason, having been found incompetent to this work, was suspended: this was attributed to a fit he had had two years before; but being an old servant, from the first commencement of the work, under Mr. Preston, and always considered as a man acquitting himself well, Mr. Barker recommended it to the trustees to allow him something by way of subsistence. Mr. Cull therefore, his foreman, was recommended instead of Mr. Hurst, as master mason, and Mr. Speers to be his foreman.

Mr. Cull being consulted by Mr. Barker, recommended that the thickness of the north wall of the dock should be increased by two feet; and to build both the walls two feet higher than they had been set out in Mr. Smeaton's plan, to which there could be no objection. With respect to the floor, they apprehended no difficulty in making it of stone like that of the gates; thinking it more eligible than of wood, as being more durable, and not subject to the worm.

Mr. Barker had the great satisfaction to find that both the outward harbour and basin had been greatly improved; as the channel under the east pier had been considerably widened and deepened: and the fullage of the basin, being now entirely and constantly kept down, betwixt four and five feet depth had been gained at the upper end thereof.

During this visit at Ramsgate, in a hard gale of wind which happened at N. E. Mr. Barker had an opportunity to be eye-witness to the more quiet and preferable state that

* Here it may be proper to observe, that had Mr. Smeaton's plan been in reality complied with, it would probably have taken the whole of this season to have completed, and laid down the timber floor; before a single stone could have been laid: but it was thought proper to begin the walls according to Mr. Smeaton's lines, exclusive of the floor.

the harbour was now in, to what it was before the westernmost part of the cross wall was taken down, and the opening made through the west pier, as has been described. The new storehouse now built by direction of the trustees, he found to be a strong and commodious building, convenient, and every way adapted for the reception of goods; as ships of 400 tons could range up close under it, and unload their cargoes with the greatest facility.

1785, Ramsgate, 5th August.—On this visit Mr. Barker reports that the dock was in great forwardness; for the walls were built up twelve feet high, and that 3065 feet of pavement had been laid at the bottom. That the gates were made, and ready for hanging; and that the whole seemed to be an exceedingly good piece of workmanship; and that it was likely to be ready for use by February next. He notices that the worm prevailed much here, and ate the wood work of the sluices to such a degree, that he recommends every part to be of stone that can be.

He had the pleasure to find every thing in an improving state; and that the encomiums which he thought it only justice to bestow upon the harbour the last year, had been more amply confirmed by the appearances in this. He says the whole body of sullage in the outward harbour was certainly considerably diminished; and the channel under the east pier improved and widened, but still not to that extent to satisfy his wishes; or that was expected from the united waters of the fifth and sixth sluices; however, as the widening of this channel was of important consideration, he ordered two of the barges to be laid close in the channel; and ten or twelve men to fill them, as had formerly been done before the sluices were brought to act. It was however observed to him by the ablest pilots and seamen best acquainted with the harbour, that it would not in reality be well to have the whole bank of sand taken away from the eastern side of the harbour; and they put a case, that supposing the harbour quite freed of this bank, and a ship coming in in a hard gale of wind, without anchors and cables; if there was nothing to bring her up, she would be liable to be driven against the walling of the piers, and be knocked to pieces; they therefore strongly urged the necessity of having a bank on the east side of the harbour upon which ships might bring up.

He notices that it had been (and not long since) the reproach of this harbour, that it never could be made capable of receiving any thing but small vessels; but that now it was capable of sheltering almost any merchant ships (East Indiamen excepted); and as a proof of it, a ship which was said to be of 800 tons, took refuge in the channel of the east pier last winter, and lay in the said channel for two months; and a large Norway ship, called

the

the Ebenezer, with upwards of 30,000 deals on board, got upon the Goodwin sands, where her masts and rigging were destroyed; yet she was nevertheless got off by the Ramsgate boatmen, and brought into the channel of the outward harbour; though so water-logged she actually drew eighteen feet and a half water; and in a gale of wind that lately, about 30 sail of vessels, English and foreign, with valuable cargoes,

of which having lost their anchors and cables in the Downs, had been brought into the harbour and basin, where they had every necessary assistance; which were then unloading their cargoes into the store-house, being leaky and much. Indeed it was, he says, now generally admitted, that within a very few years, the harbour had been improved, to a degree, even beyond what its warmest friends and promoters ever expected.

1786, Ramsgate, 5th August.—“Mr. Barker thinks it proper to acquaint the Board, that the dock is built, and is an exceeding neat piece of architecture; but the water unfortunately rises up through the pavement, a great part of it having been heaved up and loosened. A disagreeable circumstance, equally unforeseen as unexpected.—It is now perceived that there are natural springs which rise in the bed of the dock; that these, with the great weight of water in the basin, when it is shut in, united, have been so strong in their effect as not only to break through the cement, but have in many places broken the paving stones; a circumstance very mortifying, after so much pains have been bestowed upon it.” Mr. Barker, in consulting with the master mason upon the most probable means of preventing the waters rising, was informed that twenty-three years ago a new dock had been built in the King’s yard at Plymouth; and when shut in, it was found that the water rose up in the bottom, and loosened the pavement similar to what had happened here; and that no other remedy could be found but new laying the floor with heavy Portland blocks, which method Mr. Barker recommended to the Board to be taken at Ramsgate.—He says, “It is proposed to take up the present pavement, and lay down large blocks of stone three feet by four, and two feet six inches deep; each stone to be one ton and a half; and that the master mason is firmly of opinion, the weight of these blocks will effectually prevent the water from rising, and keep the dock dry.”

The stone merchants at Purbeck on being immediately written to by the secretary, returned answer, that they were not able to make stones to the dimensions required, but recommended stones of a less bulk; but as that would introduce more joints and other disadvantages, Mr. Barker took the mason’s advice, in having them ordered from Portland.

Mr. Barker had the highest satisfaction in informing the Board, that every year more and more demonstrated the utility of the harbour, as was manifest from the great number of

of shipping that in the course of the last winter had taken shelter in it, and the number of lives preserved. He mentions the following facts; a large Swedish ship ran upon the Goodwin and parted; two Ramsgate boats, at the hazard of their lives, brought the crew, consisting of the captain and twenty men, safe on shore from the wreck *. In December last, eleven ships, all of which had lost their anchors and cables off Dungeness, and several of them otherwise damaged, were brought into Ramsgate by Dover pilots; and the day before Mr. Barker left Ramsgate, a Hamburgh ship ran upon the Goodwin, and the captain and crew deserted her; but she was got off and brought into Ramsgate by two boats, one of Ramsgate and the other of Deal. She came into the basin and delivered her cargo into the storehouse (estimated at betwixt 8 and £9,000), till she repaired.

1787.—The Portland blocks being got with readiness the work of the floor was vigorously pushed during the winter and spring; so that it was completed early in the summer, which being notified to the Board, orders were sent to the master mason to put the work to a trial. In consequence, Mr. Cull's letters of the 3d and 7th August, acquaint the Board, "that agreeably to his orders he had shut in the dock, when to his great concern and surprize, and that of every one present, by the time it was high water, the greatest part of the pavement was disjointed, and hove up; and what was yet more astonishing, nearly 100 feet in length of the north wall was hove up also.

Ramsgate, 22d of August.—Mr. Barker on his visit, taking the affair of the dock into serious consideration; that the harbour being now become very useful to commercial navigation, and that numbers of vessels took shelter therein in winter, for the purpose of repairs; the dock must certainly be not only an useful, but a necessary accommodation; and considering that a large sum of money had been already expended thereon, he judged it proper to engage Mr. Smeaton to come down with Mr. Aubert to examine it, and if possible, to contrive some method to render it useful.

In consequence, Mr. Aubert and Mr. Smeaton arriving, the gates were ordered to be shut at low water; and Messrs. Barker, Aubert, and Smeaton attending the rise of the tide; Mr. Smeaton's report to the Board of trustees contains the following account: "The tide rose that day to the height of thirteen feet four inches upon the apron of the gates of the dock; but before it had risen two feet, it begun to spring through several joints of the stone-floor, which had been laid with solid Portland blocks of two feet and a half in thickness, in fashion of an arch; and which, to all appearance, had originally been sufficiently

* It is proper in this place to remark, that the Ramsgate boats lie constantly afloat, ready to put off at a minute's warning; had this not been the case in that critical moment these unfortunate men would have perished.

well

well jointed, and indeed the whole building in point of workmanship, as a piece of masonry, had been done in a very masterly manner.

"As the height of the tide increased upon the apron, the leakage through the joints of the floor gradually formed a greater depth of water upon it, so that when it was high water upon the apron, there was a depth of five feet three inches upon the floor; and we observed, that while the tide was rising, the joints of the side wall, on the north side next the basin, apparently opened, so as in some places to let water through the wall; but in far less quantity than appeared to rise through the floor *. Every thing being left standing when the tide had ebbed, so as to be upon a level with the water within, its depth upon the floor was seven feet two inches."

"The cause of these derangements, was doubtless owing to the pressure of the water under the bottom, endeavouring like a vessel swimming in the water to buoy it upwards; and which, in the circumstance of only eight feet difference of pressure (which in this experiment was the greatest) would amount to 1000 tons upon the area of floor. This power acting upwards, would indeed be the same, whatever material the floor was composed of; but from its construction, as an arch of stone laid very flat, its lateral pressure would, in this case, be much greater than the absolute weight of the wall upon its base; and therefore no wonder that it should shove it outward; and that the effects thereof should be perceived by breaking the joints of the side wall, as has been mentioned."

"He thinks it necessary to state to the Trustees, that this failure has not been owing to bad materials, or bad workmanship, or to taking a method in itself bad, but only become so, by the construction not suiting the situation and soil; for had the ground whereon the dock was founded been a stiff or moderately compact bed of clay, or a rock, either hard or soft, that would not have suffered springs to percolate through its pores; the dock built as it was, or even in its first state, would doubtless have succeeded; but it was the circumstance of there being springs issuing from the area of chalk, on which the floor was laid, that has occasioned the mischief †. And in this respect a wooden floor, according to the original plan, would have been the eligible expedient, as it would have been subject to the upright pressure only, and not to a much greater lateral pressure as in stone arches."

* The Committee's report mentions that the joints of the pavement, or more properly the coping of the wall, had opened one-third of an inch, though the wall itself was fourteen feet thick at its base.

† As I observed a considerable stream of water issuing from under the apron at low water, I ordered this water to be drained therefrom by a chain pump, and found that this spring (which was salt) vented at the rate of 160 barrels per hour, which vent exposed the bottom to the action of the tides waters.

The Committee's report states that it was Mr. Smeaton's opinion, that the whole bottom of the dock, as also the greatest part of the north wall, are so greatly deranged and disjointed, that it will be necessary to take up all the pavement and take down a great part of the north wall; and that, to render the dock secure and dry, the bottom must be laid upon a different principle, and with a different material; and the wall in some places a piece of masonry, ten or twelve feet thicker than it is at present, for which it was to make the proper designs. Accordingly, the men were immediately ordered to begin to take the wall down.

Every thing else was found in a way of doing its business, and answering its end; and in attending to the running of the sluices. It was seen that the water ran with so great a current and body, as to make its way into the harbour, apparently half a mile beyond the mouth of the harbour; but yet Mr. Barker's favourable wish of widening the channel under the east pier to a yet greater extent, induced Messrs. Barker and Aubert to take the opportunity of consulting Mr. Smeaton upon that head also; and he recommended it to the trustees, to build another sluice to the eastward of the crane, and by uniting its water with that of the fifth and sixth, the whole would have an increased effect, not only in cleansing, but in widening that channel.

Messrs. Barker and Aubert, attentive to every thing that might conduce to the improvement of the harbour, made use also of this opportunity in having Mr. Smeaton's opinion upon a point so very material and critical, that before the erection of the sluices, it could not have even been thought of; and that was, that though by the opening of the west pier, much good had been done towards quieting the harbour; yet as in very hard gales of north-easterly and easterly winds, the harbour was still liable to a greater agitation than could be wished, a complete remedy was greatly desirable. And finding that the seamen and pilots of Ramsgate had formed an opinion, that a wall or pier extended out from the east head to 350 or 400 feet in a proper direction, would greatly tend to keep out the sea, and quiet the harbour; this proposition was laid before Mr. Smeaton, and he was strongly and clearly of opinion, that such a work would render the outward harbour still more quiet; and that if another sluice were built it would, together with the good effects from it, before proposed, countervail any difference that might arise from the more westerly direction of the harbour's mouth, to take in silt, which might (not without reason) otherwise be apprehended.

It appeared to the Committee, that in the course of last winter, no less than sixty fail of shipping had been sheltered in the basin at one time, many of them brought in without anchors and cables, and otherwise much damaged, and obliged to unload their cargoes to be

be repaired; and that Mr. Rowe the pilot had actually carried a ship of 500 tons directly into the basin.

The preceding proved to be the last report of John Barker Esquire, who, with great assiduity, attention, and perseverance, had presided over the execution of the Ramsgate works for nearly twenty-eight years.

SECTION VIII.

THE unanimous choice of Alexander Aubert Esquire, Chairman, in Autumn 1787; and the subsequent transactions down to the present time.

IN consequence of Mr. Barker's death, which happened the 1st day of November, the trustees were unanimous in requesting Alexander Aubert Esquire, to take the chair; which having been done, the gentlemen observed, that from the situation of Ramsgate harbour, and the very great use it has already been to shipping, there was no doubt but it might be made of the utmost utility to commercial navigation; but as yet there remained a great deal to be done, and many works to be carried forward to bring it to that state of usefulness and perfection it was capable of; and consequently it being an affair of great magnitude and importance to the public, it required the constant care and attention of a gentleman of abilities and respectability, therefore the Board in the same unanimous and earnest manner, requested Mr. Aubert to take the lead in the management and direction of the business and affairs of the harbour, and every thing relative thereto; to which request Mr. Aubert politely assented, at the same time requesting the gentlemen to assist and support him in every measure tending to the benefit and public utility of the harbour.

Mr. Aubert being elected chairman of the Trustees of Ramsgate Harbour, a visitation was appointed, and the chairman to be attended by the secretary and Mr. Smeaton, and they arrived at Ramsgate at Christmas this year.

The first object of Mr. Aubert's attention was to render the Harbour perfectly quiet; the utility of it in its present state could not be more evidently proved than by the great number of vessels that had taken shelter therein*. It proved a hard gale of wind at east on Christmas day, so that Mr. Aubert was himself witness of the effects thereof, and saw that a great degree of agitation prevailed in the outward Harbour, beyond what before he had a conception of; he therefore assembled and consulted some of the ablest and most experienced pilots, upon the proposition mentioned at his last attendance at

* They were informed that above 70 vessels had been in the harbour at once, since they were there in August last, the greatest part driven in by distress of weather; some of them were of 350 tons.

Ramsgate, and they all agreed that there was an absolute necessity for such a work being carried into execution; and that if a pier of 350 or 400 feet were carried out in a proper direction, it would not only keep out the heavy sea that now tumbled in in hard gales of wind, and make the Harbour more safe and quiet, but that the coming into the Harbour would in reality be more safe and easy. For they observed, that at and near high water the tide runs briskly from the westward across the Harbour's mouth:

the ships and vessels that intend to make the Harbour to come down from the westward; if a pier were extended in a proper direction, they would then come along with the tide, and with more facility than at present. The only thing that appeared to them in the shape of a doubt or a difficulty, was, whether the Harbour could be as effectually cleansed from silt, that is continually brought in, as it now is *? To which Mr. Smeaton made answer, that before the establishment of the basin and sluices, such a work could not have been thought of; but there was now so great a power of backwater, which could be increased as already intimated, if there were found occasion; that if the work proposed would not lessen the facility of the entry, which in their judgement it would not, he would be answerable to keep the Harbour to as great a depth, and as clear of silt as it now is.

Mr. Aubert concluded his report to the Board, with observing, "that the works of Ramsgate Harbour have, for a series of years, been carried on without the assistance or direction of any engineer, or even a resident surveyor†, one or two occasional consultations excepted; and in those particular cases the plans of the engineer were only in part adopted. It therefore seemed to him, that in works of this nature and magnitude it was of great importance to have an able and skilful engineer; who uniting the powers of mechanism with a thorough knowledge of the materials, so as to apply them to the best advantage, might rationally be expected to be the means of saving many thousand pounds, and give durability to the works; and is consequently desirous of being guided by some professional man in that line."

"Upon these considerations Mr. Aubert has no doubt but the Board see the necessity of employing constantly some able engineer in the design and construction of their future works; and therefore as Mr. Smeaton has already been employed occasionally by the trustees, and by several of the executive Boards under government, and is well known to stand high in professional character, Mr. Aubert is persuaded the Board will approve

* Mr. Smeaton's sketch of an advanced pier was then laid before them.

† Mr. Etheridge was the only person who had been employed in this capacity, except occasionally, and whose service terminated with the year 1753.

of his being requested to take upon him the guidance and responsibility of the engineering part of the works. But although Mr. Smeaton may be induced to go down to Ramsgate periodically, and to furnish every necessary plan, as he cannot upon any consideration be resident upon the spot; it appears necessary, that he may be made responsible for the performance of his plans, that he should have some experienced resident surveyor, in whom confidence; and such a one, in case the Board should think proper to employ a resident surveyor, he is enabled to recommend in the person of Mr. John Gwyn, who has been employed twenty-seven years under Mr. Smeaton's direction as deputy surveyor; and who during that whole period has given him the greatest satisfaction in the execution of several capital works.*"

In consequence of these recommendations Mr. Smeaton was unanimously chosen engineer, and Mr. Gwyn resident surveyor.

Being now entered upon my office of engineer of Ramsgate Harbour, it may be supposed that in carrying forward the account of the transactions thereof, I am no longer under the necessity of drawing my materials chiefly from written documents, but that I may in my own person carry on the narrative; and this I am the more inclined to do, as I can state my own remarks on persons and things with much greater brevity.

1788.—In April I attended the chairman on his first visitation, accompanied by the secretary. At this time the whole of the north wall of the dock was taken down and the area cleared, and a considerable progress made with the timber new floor. Upon this visit the chairman fully opened and explained his intentions to us, the principal officers and artificers; viz. That though the re-construction of the dock was with him a great object; as when completed it would be of very great utility and accommodation to those who are driven into the harbour by stress of weather; yet he could not consider it as the primary object to which we ought to bend all our powers. It appeared to him, that the rendering the harbour a place of quiet and safety for the shipping, was to be the thing aimed at, and endeavoured to be attained, in preference of all other considerations. That therefore the works of the proposed advanced pier were to be pushed, at the same time that those of the dock might be carried on whenever it could be done without retarding the primary object; and with this view he ordered an additional number of workmen.

* Mr. Aubert specified the works executed by Mr. Gwyn, under Mr. Smeaton; viz. the Calder Navigation, the Bridge of Perth, the Harbour of Portpatrick, the Pier of Aberdeen, the Pier and Harbour of Cromartie, and the Drawbridge of Hull.

On this occasion I took the liberty to recommend, that myself accompanied by the two principal artificers, Messrs. Gwyn and Cull, should visit the stone quarries of Purbeck and Portland, to see and examine their present state and produce; and also more especially to examine the limestone quarries of Lyme in Dorsetshire, as I had been informed that the true Lyas limestone was to be had there; and which, if so, was likely to prove a valuable acquisition to these works*. This journey having been made, in consequence, the use of this valuable lime has been established here and continued ever since.

The chairman on examination found that the basin was kept clear of silt, by the use of the horse-dredges or drags, and the channel under the east pier improved; there being now good eighteen feet water at a middling tide from the harbour's mouth, up to the stairs nearest the town, and the fullages of the whole harbour visibly decreased since Christmas, by the frequent running of the sluices.

Our second visit was in June, at which time the labourers were diligently employed in getting up a large quantity of stones that had been thrown in to secure the pier head, as mentioned in the year 1774, which it now appeared were necessary to be removed in order to clear the foundation for the advanced pier. But as it seemed dubious whether they could all be got up in nine and ten feet water by the usual method of tongs from the barges; this occasioned me to turn my thoughts upon a diving machine I had formerly made use of with success in doing works considerably under water.

I had scarcely returned from this visitation before a requisition came to desire the expedient I had mentioned might be got ready, which was done with such expedition, that I set forward for Ramsgate the 6th July in order to put it in use; and the 12th left Ramsgate, after a full trial of the diving chest, and the certainty of success†.

With this machine, which enabled the workmen (or divers) therein to stay under water any length of time at pleasure, that is when the wind was moderate, that the

* I did not at this time imagine this lime had ever been used in those works, as appears to have been done; but without understanding its merits, was now grown into disuse.

† Instead of the usual form of a bell or of a conical tub of wood sunk by weights (externally applied), this for convenience, was a square chest of cast iron; which being 50 cwt. was heavy enough to sink itself; and being 4½ feet in height, 4½ feet in length, and three feet wide, afforded room sufficient for two men at a time to work under it. But it was peculiar to this machine, that the men therein were supplied with a constant influx of fresh air, without any attention of theirs; that necessary article being amply supplied by a forcing air pump, in a boat upon the water's surface.

boats could attend, in the course of that and part of the following month the foundation was cleared; and the tools for levelling of the ground, the same that were originally invented and applied by the late ingenious Mr. Etheridge, were now put in use, under the management of Mr. Cull the master mason, who had formerly been employed in that part of the business; it being the Chairman's wish, as best for the work, that every thing should be done by the same method as originally practised.

Soon after our return from the June visitation, Mr. Aubert having had the misfortune to break his leg by falling off his horse, could not attend the third visitation of this season; but I attended the secretary to Ramsgate; and the third of September we were present at the sinking of the first caisson of the advanced pier, when every thing was carried on with regularity and satisfaction; as much additional stone being built therein that tide, as would prevent its being afterwards moved by the sea; and the next day it was got up to its height; that is, above the low water mark of ordinary neap tides.

The piling of the dock's bottom was also now considerably advanced, and several of the double beams of the floor were laid, and every thing going on to satisfaction.

The Chairman being recovered, attended the fourth and last visitation of this year. His report thereon bears date 15th November 1788. It notices that the getting up of the stones (some of them in 12½ feet under water), which from the circumstances had become a work of absolute necessity, had been successfully performed; and also the sinking of the caissons of which he had the pleasure to find four in their places, and built up to their proper neap tide low water height. He also found that the fifth and sixth caissons with their materials were all in readiness; yet observing the effects that the sea had had in a gale of wind the night preceding, it having torn away one of the wooden sides of the fourth caisson, he considered that the season was far advanced; and consulting the engineer and principal officers, it was unanimously agreed, that it would be imprudent to attempt to sink any more caissons at present, but rather to do what would be likely to secure what had been done as soon as possible; and then postpone the further progress till the spring.

The floor of the dock being in a state of forwardness, above half of the ground timbers being laid, the Chairman ordered that the men should be employed in that work as much

* It was computed that about 160 tons of stones had been got up in clearing the foundation; and that about 100 tons thereof had been raised by the diving machine, many of above a ton each; but the want of the machine would doubtless have been the loss of the season.

as they could be during the winter season; but that the primary object might be kept in view, Mr. Aubert recommended, that carpenters be employed in preparing and framing more caissons; and that a proportionable number of masons be preparing the stone for the same, so that the works of the advanced pier might commence again, and be carried on with vigour, as early as weather would permit the next spring.

The Chairman further reported to the Board as follows: "that there is always a light put upon the head of the west pier at night, as a direction and guide for vessels and boats, coming in and going out of the harbour; and also that a flag is hoisted on the north west cliff, when the water rises to ten feet at the gates of the basin; and continues flying (in the day time) till the ebb reduces it below that depth, as a signal for vessels in the Downs; but as bad weather and gales of wind naturally happen in the night, as well as in the day, and consequently ships and vessels may meet with accidents from stress of weather, or from other incidental causes, and be desirous of running for the harbour for shelter, such vessels perhaps not knowing the depth of water in it, are restrained from attempting to make for the harbour, when they might do it; Mr. Aubert therefore thought it adviseable to call in some of the most experienced pilots; who unanimously agreed, that a double light always put upon the head of the west pier, in the night, when there shall be ten feet water at the gates of the basin; the additional light to be elevated about eight or ten feet above the present light, and sufficiently strong and luminous to be seen in the Downs, would be of great utility, as the double light would be a signal, denoting to masters of vessels that they might make for, and enter the harbour with safety."

Mr. Aubert (whenever the tides served) directed the water to be shut in the basin, and the sluices to be run; and had the satisfaction to observe, that they continued to operate with their usual force and power; as he perceived the water, with a rapid and strong current, carried the silt out a great way beyond the transport buoy: and that by working the dredges, and running the sluices occasionally at the spring tides, the basin is kept clear of sand. He had likewise the pleasure to inform the Board, "that the channel under the east pier is considerably widened, that it can receive and shelter a great number of ships of large tonnage, that the depth of water is considerably increased, and the whole harbour is in so improving a state, that there is the greatest probability in the course of a few years, it will become a place of the greatest consequence to the commercial navigation of this kingdom."

"Mr. Aubert embraced the opportunity of again assembling and asking the pilots their opinion respecting the advanced pier, and they professed the same belief of its beneficial consequences,

consequences, in quieting the harbour; they likewise observed, "that the present usual and safest track, for vessels making for the harbour, is to come in from the westward, and that when the advanced pier is completed, vessels will then (as now) come in right before the tide; and in all probability, with more ease and safety."

1789.—The Chairman's first visitation to Ramsgate this year, was in March, and we arrived there the 12th. The 14th the sheet piling inclosing the circumference of the dock floor, was closed in; all the beams having been previously laid.

With respect to the works of the advanced pier, the caissons were in sufficient forwardness, but it was yet too early in the season to attempt any thing at that: it had been built upon and secured, so that no damage had happened to it during the winter. The Chairman therefore contented himself with examining the state of the works, and giving the necessary directions, that every thing might be in forwardness as soon as the season became favourable.

The second visitation was the latter end of May. We then found the floor of the dock laid, and the mason-work begun: but that Mr. Gwyn the deputy surveyor, being afflicted with an abscess, was unable to attend at the yard*.

The works of the advanced pier were now going on, and four caissons had been sunk this year (making eight in the whole), and others forwarding. Upon this journey we visited and landed upon the Goodwin Sands, to have a view of them and examine their nature; and found that though of the nature of a quick sand, clean and unconnected, yet the particles laid so close, that it was difficult to work a pointed iron bar into the mass, more than to the depth of six or seven feet.

On this visitation I took several levels of the relative heights of different parts of the works compared with the bottom; also, particularly examined the lighthouse, as relative to the Chairman's last proposition to the Board.

In August the trustees assembled at Ramsgate, on a general annual visitation, and the 24th, reported as follows:

"Your Committee proceeding in their survey, ordered the water to be shut up in the basin, and have the pleasure to inform the Board, that by running the sluices three

* Of this he died in the course of the next month; a real loss to the public, as well as lamented by his family and friends.

or four times at spring tides, and working the horse drags, the basin is kept clear of fullage; your Committee likewise observed, that the channel under the east pier is considerably wider, and in its present state capable of receiving a number of ships of 500 tons and upwards; and it is acknowledged by all persons acquainted with the harbour, that it has been wonderfully improved within a few years past, as in the most useful parts of the harbour there is an increase of between five and six feet water; and we contemplate it in its present state, and peruse the evidence given at the House of Commons, prior to the passing of the Act of Parliament, and also the preamble to the Act, will be convinced that Ramsgate Harbour now exceeds the hopes ever entertained by its projectors and friends; or, that the legislature had any idea of, at the passing the Act, which supposed it might be made a receptacle for shipping of and under 300 tons, but could not imagine it ever would be capable of receiving ships of much larger burthen. That the harbour is of great importance to commercial navigation, the well attested documents of the office sufficiently prove; videlicet, That the harbour (under Providence) has already been the means of saving property to the amount of between three and four millions sterling, and between eight and nine thousand valuable lives, to their friends and society; yet notwithstanding the truth of these striking facts, the present useful state of the harbour, through prejudice or want of proper information, not being known to the public as it ought to be, your Committee think it necessary to recommend, that Mr. Smeaton your engineer be desired to draw up a proper account of the harbour in its present improved state, to be published at a convenient time."

The walls of the dock were then up seven or eight courses high; the whole design of it was fully apparent to the Committee.

The seventh caisson was now sunk, while the Committee were there; and every thing being in a state of going on successfully and satisfactorily, the Committee signified their wish to see the operation of the diving machine or bell (as in conformity to custom, it had now acquired that name,) for it appeared to the Committee, that by means hercof it would be very practicable at any time to examine the state of the foundations that had been laid a course of years; and particularly, whether the timber bottoms of the caissons, that laid under the piers, and immediately upon the chalk, had not greatly suffered by the worm? and further, that by the same means, it would be practicable to make in future any repairs to the foundations that might, on account of the above or any other cause, be found necessary.

On

On this occasion, I had the honour to attend the Chairman down to the bottom of the sea, upon which we could stand, and work dry. In this situation the Chairman finding himself perfectly at his ease, and very comfortable, staid full three quarters of an hour. We found that the ground work, that is the bottoms of the caissons, was now so deeply buried in sand and silt, that it would be a work of considerable labour to rid it out and clean it; and as this is doubtless the best defence against the worm, he concluded it inexpedient to attempt to disturb it: having fully satisfied himself of the practicability of staying any length of time, and of performing any kind of work, that the bounds thereof admitted, with a capability of removal almost at pleasure, we gave the signal for ascending, and were received with great joy by our friends, whom we found surrounding us in boats, and who by this time were beginning to be apprehensive that something might have happened to us.

This visitation I took an exact plan of the west pier head, to enable me to make out a design for a lighthouse for the approbation of the Board, for erecting a double light upon that head.

The Chairman's last visitation of the year 1789, was November 7th. At this time, though the weather had lately been but indifferent, yet eight caissons had been sunk, and fixed this year; which, with the four sunk the last year, completed twelve in two years, as we originally had in view. The Chairman consulting the engineer and principal officers, considered that those twelve caissons would need to be secured; and that the best way to do this was to build the superstructure upon them, with all possible diligence. And furthermore, that it would be eligible, rather than completing any particular part, to go on with the whole length, which being now 120 feet, that is, nearly one-third of the proposed advanced pier, if weather permitted, that it could be got up to high water mark by Christmas; this would be sufficient to demonstrate the effect that was likely to be produced, and would be of great service, in affording an addition of shelter to the shipping the ensuing winter; in short, it would give us an experimental proof of the good or ill that was likely to arise from the farther prosecution of this work; and the harbour having been founded, nothing so far appeared but what was in favour.

It also had happened in the late autumnal winds, that the break-water or jetty in the external angle of the east pier with the land, had been washed down and totally demolished. This was a work that had been erected several years before, chiefly of old ship timber, by way of experiment, for the defence of the pier, and the establishments there. This having, with frequent repairs, answered the end ever since, it appeared therefore

therefore very desirable and necessary to be rebuilt. This being the case, the Chairman thought it ultimately for the greatest benefit to the harbour, to rebuild it with stone, and in the most substantial manner, being greatly exposed: and I was ordered to prepare a proper design for a stone break-water or bulwark, for the approbation of the Board. Here therefore were two objects that wanted to be prosecuted both at once; and both with our whole force; but as the break-water could not be more than totally destroyed, which it then was, the Chairman judged it of the most importance, both in point of safety and use, to carry on the advanced pier till it was got to its height; which was done in the course of this year.

1790. This year commenced with the building of the break-water. In January many heavy gales at West came on, which of course detained the shipping in the Downs, many of them therefore sought shelter in Ramsgate Harbour, and found it in a degree never experienced before; so that in the course of this month, there were in it at one time 160 sail, the greatest part of which lay in the basin, and there was room in the harbour for many more. This assemblage of shipping afforded a spectacle so new, that the people all round the country came to see it.

The chairman's first visitation this year was the beginning of March; but the getting up of the advanced pier, and after that of the break-water, having totally occupied the masons, the dock was obliged to remain as it had been left the last spring. The break-water was now in a state of proceeding very vigorously; but it being too early in the season for any thing to be done at the advanced pier, the chairman could only give the necessary orders, that nothing might hinder the proceedings when the season was more advanced.

The beginning of April a very hard gale of wind happened at E. S. E. and the capping course of the break-water not being quite closed in, the violence of the sea washed stones of one ton and a half out of their places, though every thing that had been completely fixed, stood fast. This, however, shewed us that we had not bestowed on this work more solidity than necessary, as some had been induced to imagine. The violence of the sea also fell so heavy upon the advanced pier, that the extreme unfinished termination became underwashed, and caused a settlement of the exterior angle, which immediately obliged Mr. Cull to guard it with rough stones, in the manner the original pier-head had been before the removal thereof; and likewise to take some of it down, in order to straighten the wall.

Thursday

Thursday, 27th May, the Chairman arrived at Ramsgate, upon his second visitation; and then found the break-water completed; the damage at the advanced pier rectified; and two caissons, viz. the 13th and 14th ready to be put down, and which were sunk while we were there. We saw the sluices run; examined the channel, and found it without any material alteration from the prolongation of the advanced pier.

Thurs. 12th August, the general visitation of trustees took place, at which time the eighteenth caisson was sunk, the works examined, the sluices run, and every thing found satisfactory.

Six caissons having been laid this year, - finding ourselves too late in the last season, by laying eight, it was thought best by the Committee to terminate the work of this season, - to the laying down of caissons; and employ the remainder of it in getting the pier built up, so that every part might be seasoned before the winter and heavy gales come on: and as there would now be full 180 feet of the advanced pier laid, this, when raised to its height, would be an effectual trial of the utility, effect, and validity of this work.

The Committee had the satisfaction to observe a very visible alteration in the width of the channel under the east pier, which had been chiefly brought about by the running of the sluices, during the crowd of vessels in the harbour in January last.

Upon the Chairman's fourth visitation of this year, we arrived at Ramsgate the 21st October, and then found the present stretch of advanced pier in general up to high water mark.—During our stay here, we had a hard gale of wind at east, for three days together; and then had the great satisfaction to find the harbour, which when the wind was at that point used to be much agitated, to be most remarkably still and quiet; so great a change in this respect could have scarcely been expected, till the pier was carried out to its full length, of which what was now done was somewhat more than half. On this occasion we thought it necessary to compare the harbour-master's soundings, taken in May last, and also the present month, with our own now taken in his presence; and on comparing them, had the satisfaction to find the channel of the harbour, notwithstanding the advancement of the pier, to be in an improving state in depth as well as in width.

The

The present State of Ramsgate Harbour.

THE operation of the sluices, as has been described, has gradually cleared out a broad space or channel through the middle of the outward harbour, from the gates to the pier heads; and the bottom lying upon a gentle slope, makes above six feet more water in that material part now, than in the year 1774, so that vessels drawing from ten to eleven feet water, can go into the basin in neap tides; and in spring tides those drawing from fourteen to fifteen feet.

Under the curve of the east pier, the sluices have now cleared a channel capable of taking two ships abreast, with clearance for passage, where at neap tides there is from sixteen to seventeen feet water, and at spring tides from twenty to twenty-one feet, and often twenty-two; so that not only vessels of 300 tons, the primary object of this harbour, may come into it in all tides; but at spring tides as large ships as are ordinarily employed in the merchants service. It is here in reality no material objection, that a vessel cannot come in from the Downs at low water; because she is not in distress there till the tide is risen to that point of height that it begins to run northward, and then it has been amply shewn, that there is always water to go into Ramsgate; and that with every wind whereby she can be annoyed in the Downs, she will be right before it into Ramsgate; and every wind that will be fair for ships to proceed upon their voyages from the Downs, will be also fair for their sailing from Ramsgate.

If therefore it be really eligible to have a harbour for the reception of ships in distress from the Downs, it must be upon the flat shore of the Isle of Thanet; and no place has yet been pointed out so proper as Ramsgate.

It probably will be thought by many who cursorily view the place, and are not fully apprized of the requisites of an artificial harbour, to be a defect, that this harbour is not entirely covered with water all over its area at low water; but the bank is really of the greatest utility, as will appear when the pilot's representation above noticed is fully considered. However, notwithstanding that for the reasons already mentioned none of the sluices have been brought to play upon the bank, yet it has in reality so much wasted, that the highest part of what now remains is lower by five feet than the middle of the harbour was in

in 1774; and indeed it is so far wasted and wasting, that probably it will not be many years before expedients will be found necessary to preserve it. There have already been complaints, that it is grown so low, that at neap tides the vessels cannot get their ballast therefrom; and the expedient of filling barges in readiness has been ordered by the trustees for a remedy of that defect. At a spring tide there is now thirteen feet water over it, so that the smaller vessels may occasionally lie upon it.

Besides the completion of the advanced pier and works now in hand, there is obviously a number of articles of considerable expense, that will greatly tend to improve, strengthen, and confirm the whole work; and which may very well be expected, after the various councils, turns of fortune, and changes this work has undergone, are considered. And after all, a harbour that must subsist by the artificial power of sluices, must be subject to a continual expense, and great care to keep every thing in repair and in order; but when all those things are duly, properly, and attentively performed, I doubt not to see the time when it will be said, notwithstanding its misfortunes, and the obloquy that has been occasionally cast upon it, to be a work worthy of the expense it has incurred, at least by the attempts to recover it from the condition it was in in the beginning of the year 1779. I will conclude with saying, that according to my information, 130 sail of vessels were at one time in the harbour, driven in by stress of weather in the late winds of January 1791, among which were four West Indiamen richly laden, from 350 to 500 tons; and if we are to suppose that the whole or the greatest part of these 130 vessels would have been riding in the Downs during this stormy weather, we need not be at a loss to judge what a number of additional dangers and difficulties would have been in the way of those which actually did ride there. I understand that the number of vessels in the Downs at one time has rarely ever exceeded 300 sail; but in the bad weather in the beginning of the year 1790, and in the present year, the Downs were in a great degree cleared, there being in reality few ships left riding in them.

A List of the number of Ships and Vessels that have taken shelter in Ramsgate Harbour in stormy weather:

In 1780	-	29	In 1786	-	238
1781	-	56	1787	-	247
1782	-	140	1788	-	172
1783	-	149	1789	-	320
1784	-	159	1790	-	387
1785	-	213			

Among the above were several from 300 to 500 Tons burthen, and upwards.

Within

Within the last seventeen months upwards of six hundred sail of ships and vessels have taken shelter in the harbour, of which above three hundred were bound to and from the port of London.

Evidence can be produced, that the harbour has been this winter the means of saving a great many ships and vessels, and property to the amount of between two and three hundred thousand pounds, with a great number of valuable lives, which *otherwise* would have been driven upon the flats and rocks, and in all probability lost.

As an addition to this Report I have the pleasure of informing the public, that, on the 17th July 1791, at a high spring tide, the new dry dock built in the basin for repairing ships was tried in the presence of the chairman, for the first time since it was found necessary to build it with a timber floor, which is of a new and peculiar construction, on account of the springs from the chalk rising so powerfully under it as to force up the stone floor with which it had before been twice tried. The experiment answered in the completest manner; the dock remaining perfectly dry till low water, when the sluices of the basin were opened for scouring the harbour, so that this very desirable object, that has been so much despaired of, is now fully obtained, and must prove of great utility to the public.

SANDWICH HAVEN.

The REPORT of JOHN SMEATON, Civil Engineer, upon the State of Sandwich Haven.

To the Mayor and Magistrates of Sandwich.

GENTLEMEN,

THAT according to historical accounts Sandwich was once a famous and flourishing sea-port, and that the Isle of Thanet was completely surrounded with navigable water, there is not the least reason to question; for the change from that to its present state, without supposing any particular convulsion of nature, or neglect of particular persons, is conformable to the regular change that is constantly experienced in all similar situations; the mud wherewith the sea-water is always charged in a greater or a less degree, being ready to subside and fix wherever it can meet with a place of rest. The great cause whereby it is kept suspended, is the movement and agitation of the waters that contain it. Wherever the quantity and agitation of the water are too little, or the quantity of mud is too great to be kept in motion by the agitating powers, its natural tendency to rest will operate; and the effects of want of motion increasing in proportion to the progress made, a more rapid change ensues towards the completion of nature's operation, than in the more early stages. Every creek, inlet and bay, that has not a sufficiency of fresh water rivers to keep it open by being discharged through it, has a tendency to become land. While such creek or bay remains deep, a quantity of tide's water flowing in and out twice a day, tends to keep the mud in agitation and from settling; but as the tide of ebb is naturally weaker than the flood, the ebb will not carry out all that the flood has brought in; and when the deposition is so far advanced as to contract the breadth of the water, and render it to a certain degree shallow, the quantity of water flowing in and out being lessened, its power is weakened. The natural means whereby an inlet is kept open, is the discharge of a fresh water river through it, which opposing the influx of the tide, and adding to the force of its ebb, will always maintain a certain channel in proportion to the quantity of land-water that requires to be discharged. The tendency of nature therefore is to contract the channel to such a size, that the natural power of the stream can just maintain it; and in this state the wide extended arm of the sea, anciently flowing by Sandwich, and up the general vallies, as now called, seems to have been at the period that the new cut at Stonar was projected and executed.

A river such as the Stour, is by no means adequate to keep open so large an arm of the sea as that through which it flowed in former ages; and the powers of its current having become considerably weakened by the meandering course it took, (which in effect lessens its declivity) the difficulties of draining the marshes and adjacent low grounds became greater in proportion as the depth and width of its channel grew more contracted. Thus, while so obvious a remedy presented itself as the turning of the river through the narrow neck of land at Stonar, where, in the space of a furlong, there was not more than a fathom; it is not to be wondered that the landed interest in the river, was eagerly wishing to seize the apparent advantage, and indeed so happy and easy an expedient rarely occurs in subjects of drainage. The late Mr. Yeoman in his report, speaks of having had experience of other rivers under the same circumstances; for my part I have seen many rivers; but the Stour in this respect stands alone. Could Sandwich have been as easily moved to Stonar, as the Stour carried through this cut, every thing would have been well on all sides; but notwithstanding the assurances of Mr. Yeoman, it certainly was contrary to the experience of us all, to suppose that the running of the height of the flood waters by another channel should tend to improve the harbour of Sandwich; unless he meant that part of the Stour that lies below the new cut at Stonar, to the sea, as being the harbour of Sandwich, of so much importance to that town. The thing is however now fixed; and under certain regulations by an Act of Parliament, which cannot be deviated from by either interest without the consent of the other. But it appears to me that there is nothing to hinder a different mode of operation by consent of parties; if it can be made appear, that they both will be bettered by the change; and this I will now endeavour to point out.

It is the great land floods proceeding from great downfalls of rain, or dissolution of snow, or both conjointly, that is the great operative cause in clearing the channels of rivers to sea; and this chiefly when the tide is out; and most of all when they happen at the low ebb of a spring tide: at such a time more work is done in a few hours than could be done in months by a leisurely or moderate reflow; this may, as the engineers affect to term it, grind away a little of the mud, sand, and silt; but the former tears it away with violence. A gentle reflow, experience evidently shews, disturbs not a particle of sand or mud; on the contrary, if the preceding tide of flood has had power to bring in a quantity of silt along with it, such a reflow will give it leave quietly to subside; and where nothing is done towards its removal in one tide, no number of repetitions will amount to any thing. It seems therefore to little purpose for the Harbour of Sandwich, I mean that part of it that is contiguous to the town, when the top waters are drawn off through the flood gates of Stonar, to leave the dribblings of the floods and ordinary current of the river, to go quietly round by the way of Sandwich.

The

The work being now executed is not, as before the passing of the Act, a matter of speculation; the effects may be evidently seen and with more certainty judged of. I must take for granted that the standard mark was fixed as the law directs, at the medium of nine feet above the bed of the river at the head of the cut: let any one now sound the depth of it for some space below the head of the cut and he will perceive how miserably it is here diminished, both in depth and width. This evidently shews how much the water has lost of its cleansing and scouring power, since the passage of the top waters have been diverted. On the other hand let the channel of the Stour be viewed above the head of the new cut, he will soon perceive how greatly it is augmented; how striking the contrast! all this in favour of the drainage.

For my own part I am professionally as great a friend to drainage as to navigation; and therefore if I can shew, in consequence of what has occurred to me from the view I have taken, how the drainage may be very materially improved, even beyond the advantages already gained, by means that will improve the navigation also; and that without any new charge, I shall be doing ■ evident service to both.

I have always understood, and believe it to be true, that the flooding of low grounds in the vallies of rivers is an advantage to the grounds, provided it is done or happens at suitable seasons of the year; for the fresh waters that come down from the high grounds in floods, constantly bring with them a quantity of soil enriched with the manure that washes down from the higher country, which being deposited upon the surface of the low lands, very greatly improves their fertility. It is the misfortune of low lands which are not in a state of perfect and ready drainage, that the water when brought upon them by the winter rains is apt to lie upon them so long in the cold season of the year, that it greatly damages the roots of the useful vegetables (which in general are not aquatics), so that the occupiers of these lands, losing much more by the continuance of the water upon them than they gain by the deposition, generally reckon and imagine they never can get them dry too soon. Now, suppose at the beginning of a flood, if the waters were kept upon the surface of the vallies for a fortnight, they would be fertilized thereby, provided they were run off more speedily afterwards than they used to be. The height or depth of the water upon the land is not what does the damage, but the contrary, the injury arises from its long continuance at a small depth; and in cases of difficult drainage the difficulty has not been to get rid of the top waters, which by their height have a greater declivity to the sea; but the bottom waters, by the riddance of which the ground is made competently dry and fitted for the purposes of agriculture.

Imagine now in the winter months ; suppose, November, December, January, February, and a part of March, that instead of drawing the gates when the water was just above the mark after a dry season, they were to remain shut for a certain number, suppose for three or four days, that the water might completely overflow the meadows and take its ancient course ; that then the gates were drawn, and without being restricted to wait for an hour's ebb on the haven side, and then to run only for five hours each tide ; were to run them as soon and as long as the land flood water would overflow the side, for the space of four tides running, then let them remain shut for four tides, and four tides run as before ; and so alternately, four tides and four tides till the flood was run off, and the water never rose in the time shut to the standard mark.

In this way it is very certain that not so much water would run through the flood gates in a given number of days, than can do in five hours each tide ; but by drawing lower in consequence of a continued draft, the descent of the water from the meadows would be more quick and effectual, and particularly so in the decline of floods. On the other hand the greater abundance of top waters that would this way be forced to pass Sandwich Bridge, would much more effectually tend to keep the whole channel of the Stour open, in its long meandering course from the head to the tail of the new cut, than it can now do, when it is never suffered to have its full effect, owing to the constant diversion of a great part of it by the new cut. By this means a scouring power would act at intervals through Sandwich Harbour, of much more consequence for the reasons given, than the weakened one it can now have ; and which, combined with the advantage that the lower part of the haven, from the tail of the cut to the sea, must necessarily receive from the flood gates, appears to me sufficient to keep the harbour of Sandwich in as good order, as it has been known in the memory of man ; provided a little help from the hedge-hog and spade be given in some particular places.

The harbour of Sandwich, properly so called, I find is complained of rather on account of its growing narrower than shallower. The contraction of its section is a natural consequence, of the loss of the force of the top waters of the land floods ; but I think it is particularly fortunate that the contraction has rather been in width than in depth. The expedient therefore that I have proposed will, together with the means already used, in all likelihood recover the former width, or at least prevent a further contraction.

When a fresh water river makes its way to sea through the loose sand and silt that the sea has originally deposited, its course is continually varying, as there is nothing stable to fix it ; for when by any accident it gets into a curve out of a straight line, the water by its

its superior action on the concave side of the curve, tends to make it more curved. To attempt to cut off the points by the spade is an endless and therefore an useless work. Nor can the matter be mended by jetties, because these will make curves where there were none before. All that can be done to the purpose in this case, is to alter the perches and buoys conformably ; so as to point out the channel.

Upon the subject of the outward haven, but the harbour* of Sandwich in reasonable good order ; indeed in better than I could have expected, considering the natural difficulties to its subsistence ; and especially since the total subtraction of the top floods from the harbour ; which affords an instance what a little help will do when properly and seasonably applied, as I understand the hedge-hog has been made a considerable use of ; for when the water runs with a strong current, a great deal of sand and silt will be carried by it down stream to seaward.

The river Stour above the limits of Sandwich Harbour grows sensibly more and more contracted and obstructed with weeds, till we arrive at the head of the new cut. This district in several places wants the spade as well as the hedge-hog, which I also understand to be here used by the Commissioners of sewers ; and it appears to me that every year this evil will increase, unless prevented by the different mode of running the flood gates I have recommended, and which will be by far the cheapest expedient.

The Commissioners of sewers in this way, will also be relieved from the necessity of maintaining the new cut at the width of 40 feet ; the fulfilling of which condition I expect will otherwise occasion a very considerable expense ; as the operation of the flood gates seems likely to widen it apace.

I shall conclude with observing, that what I have recommended being a matter of stipulation, may be tried for a year or two certain, till the effect of it is seen ; and then a more solemn engagement entered into, as the effect of such experience shall evince.

Grays Inn,
15th August 1789.

* This distinction seems necessary to avoid ambiguity ; the haven being supposed that part between the tail of the new cut and the sea.

DOVER HARBOUR.

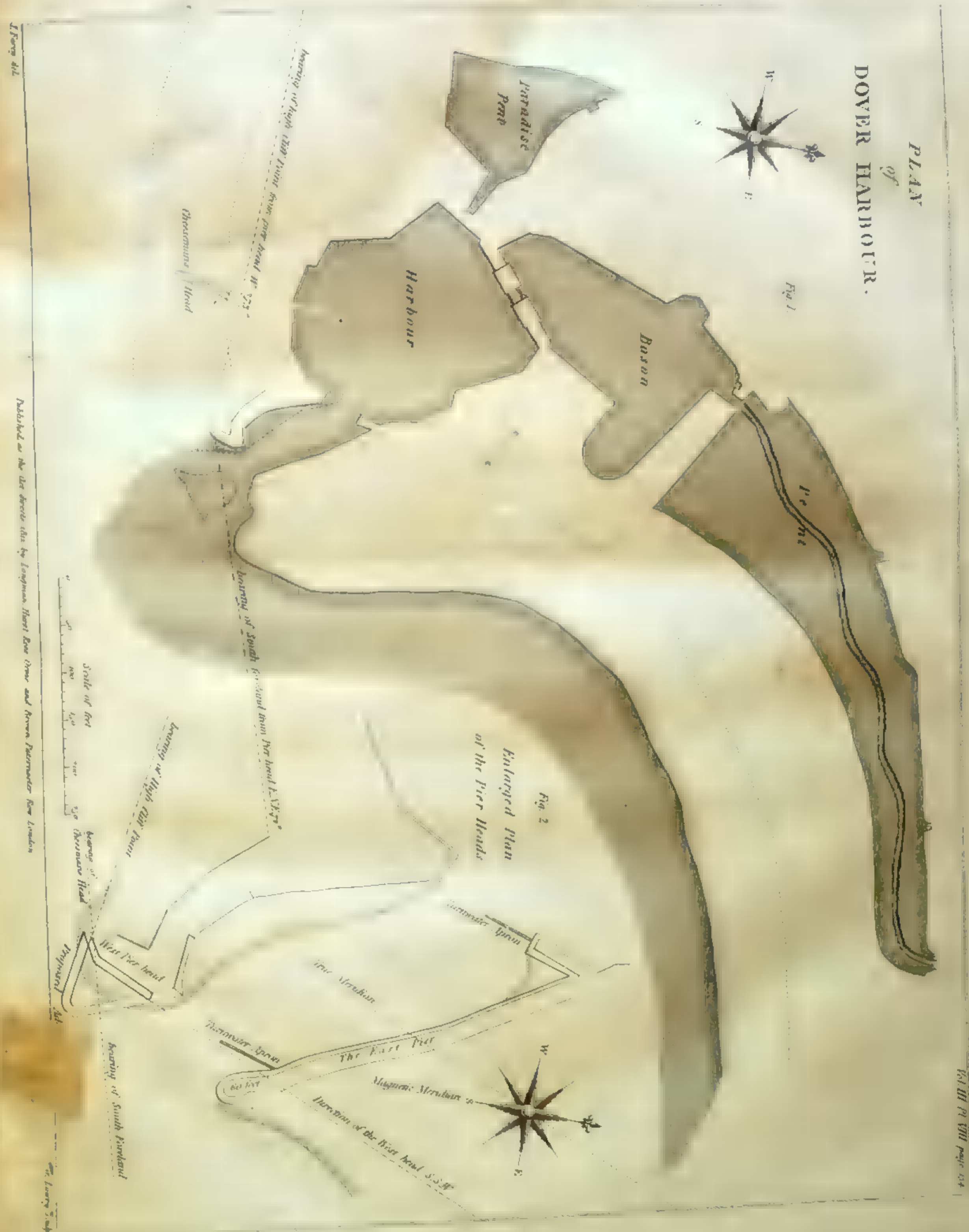
(See Plan, Plate 8.)

The REPORT of JOHN SMEATON, Engineer, upon the Harbour of Dover.

THIS harbour appears from old accounts to have been a national object for ages past, as being the nearest port, and consequently from its situation the key between England and France; on this account great sums of money have been from time to time expended in keeping it open and rendering it as commodious as the nature of its situation will admit; yet notwithstanding every endeavour for this purpose it still labours under some natural inconveniencies, which it is greatly to be wished were removed. For this purpose, at the desire of the Right Honourable the Earl of Holderness Lord Warden of the Cinque Ports, I went down to view and examine the harbour of Dover in February last, where I had every assistance the place would afford.

The port of Dover has in length of time gone through many changes; the mouth or entry thereof being at present in a very different place from what it was within the compass of record, as appears by accounts thereof collected by Mr. Hammond of Dover, with the perusal of which he was so obliging as to favor me. This great change has been evidently brought about by the same cause that has at all times been, and still continues to be its greatest annoyance; viz. the constant motion of the beach or shingle which by the action of the seas is driven coast ways from west to east; for as the British channel opens to the west and contracts to the eastward, the seas are much more violent and heavy from the south-western than from the south-eastern quarter; and in consequence, though it may be apprehended that on violent storms at S. E. the shingle may in some degree be moved westward, yet the general prevalence being the contrary way, the most apparent and observable motion is coastways from west to east.

This shingle or beach (as it is called) consists chiefly of flints that seem to have originally proceeded from the chalk cliffs that invest a considerable part of the south coast of England; which cliffs being gradually undermined by the action of the seas at the foot thereof, tumble down, and often in very large quantities; where by degrees the chalk dissolves by the action of the sun, the sea, and the frosts, and the flints being broken and incessantly rubbed



rubbed against each other, form a constant succession of beach. This however is observable, whether this succession is to be attributed to the above or any other cause, that an immense quantity of beach is in a state of continual motion along the coast from west to east, part of which lodges and fills up every recess where it can be deposited and lie in quiet.

This beach has formerly been the destruction of the old harbour, and it appears from the above accounts that the mouth has been more than once entirely shut up, and has remained so for years; and that the mouth of the present harbour was originally a cut through the beach to let off the land waters sent up in the inside of the harbour, in order more effectually to view and examine the state thereof, and to enable the engineers to construct such fresh works as might be necessary for its re-establishment.

From this state the present harbour has been gradually improved; the entry whereof is defended by two piers composed chiefly of wooden piles, the inside filled with rough heavy stones. After passing the throat or entry, the vessels arrive in a capacious outward harbour, where they may lie defended from all winds; but having an open communication with the sea the water flows and ebbs therewith, and at low water spring tides the whole is left dry. Above this the natural capacity of the harbour (as it seems) is divided by a dam, or as it is called the *cross wall*, in which is an opening of 38 feet wide at top, and about 36 at bottom; and in this is placed a large pair of gates pointing to landward, through which vessels at high water may pass out of the exterior harbour into the interior harbour or basin (as it is called) where occasionally they are kept afloat.

This cross wall besides the great gates, has two other openings of about twelve feet wide, in each of which is placed a pair of draw gates.

The interior harbour or basin is again divided by a second dam or cross wall having an opening of more than 20 feet for the passage of smaller vessels, which is also furnished with a pair of gates pointing to landward; this dam has likewise another opening furnished with three draw gates, by which the water can be occasionally let off so as to scour the basin. Into this upper reservoir, which is called the *Pent*, the fresh water river which springs from the chalk hills north of Dover empties itself, and makes its way through both sets of gates, through all the three harbours, and lastly betwixt the pier heads to the sea.

This general disposition of the harbour appears to me as judicious as can be contrived, and is upon the same general idea as the port of *Cherbourg* upon which the French had expended an immense sum of money, in order to compleat every thing in the most substantial manner, before it was destroyed by the English in the last war.

According to this disposition, when by hard gales of wind and seas from the south-western quarter, a quantity of beach is brought round the western head and lodges itself between the heads; the basin and pent are then filled partly by taking in the sea water and partly by fresh-water afforded by the river, and there retained till it be low water. The draw gates of the sluices in the cross wall are then opened with all possible expedition, and the body of water contained in the basin and pent, by making its way between the pier heads cuts down and removes the bar of the beach, which at the time of spring tides is done with so great effect, that at one single operation, as I am informed, a good passage is opened for vessels; and at two tides the whole mouth of the harbour can be cleared; and could this be done with equal ease and expedition at all times when wanted, then would the evils that are now complained of not subsist, and this port would be in nearly the best condition its situation is capable of; and which indeed is very respectable as a tide harbour, having a good capacity, with from 16 to 18 feet water at common spring and from 11 to 13 feet water at common neap tides: but it so happens when there are storms or hard gales of wind from the south-western quarter and at the same time short or low neap tides, that such a quantity of beach will be lodged between the pier heads, and to so great a height, that according to my information a vessel drawing but four feet water can hardly get into or out of the port, at a time when if the mouth were clear as usual, there would be good ten or eleven feet water into and out of the outward harbour.

At those times there remains at low water so great a depth without the heads, that the water from the sluices has not a sufficient fall and power to drive out the beach from between the heads, but it is obliged to lie till the spring tides come on; which as it may sometimes happen to be an interval of a week, produces great obstruction to the packets established between Dover and Calais, as well as to the mercantile trade of the place; and yet more to general trade, as vessels may want the port for safety during these intervals but cannot enter it.

The remedy for this evil, or as far as it is capable of remedy, is as I apprehend the object of the present enquiry; and towards this end two general methods present themselves; viz.

1st. The

1st. The prevention of the beach from getting into the harbour's mouth, and

2dly. A more effectual way of clearing it out when it happens to get in at the times above specified.

It has long been observed that when, by the washing of the sea at the foot of the chalk cliffs, any considerable fall of the cliffs happens to the westward of the port, this ground so fallen making a projecting point or promontory further out than usual stops the course of the beach coastwise, so that when the quantity which happens to be laid eastward of the falls (as they are called) has got beyond the port, the quantity passing the pier heads is so small that the port is very little annoyed therewith; but as those falls are chiefly composed of chalk, and much broken by the shock in falling, the sea in the course of a few years washes them away, and then not only the beach is let to pass in its ordinary quantity, but also the quantity before retained by the falls, which gradually escapes as the fall (or artificial point) washes away. This has given occasion to a supposition, that if instead of these temporary promontories (which are often so considerable as to cover some acres of ground), fixed heads or jetties were run out into the sea, which were not capable of being washed away, they would for ever prevent the beach from getting eastward into the harbour; for, say they, so long as these falls or natural jetties last, so long is the harbour free from beach; especially in such quantity as to prevent its being easily kept clear by running the sluices, and therefore is no annoyance thereto. This matter, as it depends upon facts that are in themselves at first sight striking, and on that account strongly insisted upon by many, I shall endeavour to set in a clear light.

When I was at Dover in the month of February last, a very large fall, about three miles to the westward of that port, had happened but a little while before; as well as another large one nearer to Dover, which had happened some time previously; both these falls I went to view and considered very attentively. I judged that the great fall (as had been represented) covered six or eight acres of ground, and will undoubtedly take a considerable time to wash it away. I observed that the quantity of beach lining the shore gradually diminished, as we approached both these falls from the eastward, so that near thereto the shore was in a manner clear of beach on the east side, while there appeared to be a quantity gathering on the west sides, and which was in a state of increase, as must necessarily happen by the gradual approach of the beach from the westward.

Undoubtedly till these promontories get charged to the full with beach, the greatest part will be there retained, and in consequence the constant supply being cut off, the quantity eastward

eastward of the falls will gradually diminish by removing still further east. That these falls if rendered permanent would permanently retain a quantity of beach sufficient to charge them, and in consequence make an addition to the coast for some space westward thereof, I can readily admit; but that after they are full charged with beach they will continue to stop the constant supply from getting round these heads, and again driving along the coast eastward as it had done before, is what is by no means clear to me. The matter rather presents itself to me in this light; that in fact by such time as these falls get fully charged with beach, or perhaps sooner, they get so far washed away as to begin to loose it again; and as by this means their power of retention, *after they are full*, never comes to the proof, this makes it to be imagined that the beach begins to move eastward merely in consequence of the falls washing away; and therefore had the point been permanent, the beach would always have been stopped.

That the time taken up in the washing away of these falls may in some measure correspond with the time they take to fill, appears hence, that the largest falls are the longest in washing away; but then they will confine and lodge more beach before they are full. I can therefore readily admit that if jetties were run out to the same length as those falls, they would if properly maintained permanently retain a *certain quantity* without afterwards letting that quantity go again, as the temporary falls or jetties now do; but as I am no ways convinced that they would tend to stop the constant succession of beach from getting round their heads after they are full, and then driving along the coast as before; I am of opinion that the good that is to be got to Dover harbour by raising artificial jetties in order to lock up a certain quantity of beach as in a chest, will be no ways adequate to the expense of raising them, but that the successive quantity will in fact fill them as fast as they can be carried out by men's hands; so that ■ remedy this way must consist in an eternal work of building jetties, which as they will require maintaining as well as building, will, together with the common repairs of the harbour works, induce a very great expense.

It is said indeed, that though the heads may not retain the beach beyond a certain quantity, yet that if it be forced to go out into deep water, it will be lost in the sea and never return upon the coast. But in answer to this, I fear it will not be possible by the hands of man to carry out those jetties into such deep water upon this sloping coast, as to prevent their return; nor indeed, when I observe how oddly this beach gets along the coast through passes where it must go through deep water, and afterwards appears again, I am not inclined to trust altogether to the shoving it out into deep water, even if it could be done. I am therefore more strongly induced (without neglecting any advantages that

may

may be drawn from those casual and temporary reliefs of nature, the falls) to confine my views, operations, and expense to such purposes as have a determinate end, and which suppose the best to be made of it that can be, under the supposition of a constant succession of beach from west to eastward upon the coast ■ heretofore.

Conformably to this doctrine of the movement of the beach, may be reckoned the real benefit found by the jettee that has been erected at the Castle Point. It seems that formerly the breadth of ground between the pent and the sea was so narrow, that there was great danger of the seas making a thorough breach into it; but that upon a large fall happening at the Castle Point, ■ quantity of beach was lodged and the partition between the pent and the sea was greatly strengthened as long as the fall lasted; but upon the washing away of this fall the barrier was again greatly weakened; which being observed, an artificial pier or jettee was erected at the same place, and ever since the beach has been so far retained as to lie in a considerable breadth and strength between the pent and the sea, and so ■ to put that matter out of all danger. This was certainly a very judicious piece of work, and the effect was fully accomplished, that is, of retaining a quantity of beach to the westward of it, so ■ to make ■ addition to the coast; but this being once made to as great ■ degree as the projection of this head is capable of retaining it, the further quantity coming from the west and passing by the mouth of Dover harbour, is not retained by this head but gets round it, is again gradually washed up upon the shore, and pursues its former course, and probably gets round all the heads and forms the beach in the Downs.

To the westward of the harbour's mouth is erected ■ pier, jettee, or breakwater, called Cheefe-Man's Head, whose effect has likewise been to lock up ■ quantity of beach, and thereby to make an addition to the coast. While this was doing, the good effect thereof to the harbour was experienced, but being now in ■ state of decay, the beach it formerly retained is coming down; however ■ the natural supply will undoubtedly be cut off for some time by the falls to the west, it seems to me, on mature consideration, to be more adviseable to take the benefit of this intermission, and to employ the present powers in raising a work that will more permanently and directly tend to the relief of the harbour than the repairing of Cheefe-Man's Head.

The natural direction of the entry of the harbour is S. E. by the present magnetic meridian, or about E. S. E. by the true meridian; but to avoid confusion I shall confine myself in the mention of the points of the compass to the magnetic bearings only. The shape of the western head is not only very uncommon but to me very extraordinary; for

after it has been carried out in the natural direction of the harbour's entry, for about 30 feet, in a line at or about S. S. E. it suddenly turns away to S. S. W. in which direction being carried on between 60 and 70 feet, it is terminated with a salient angle pointing to the same quarter. The line of direction of this flank of the pier being continued in an opposite direction, cuts within the eastern pier head about 60 feet, so that with all winds betwixt S. S. W. and E. S. E. this flank is struck obliquely by the seas, and acts in the manner of a tunnel, towards bringing the seas (with wind from S. to S. S. W.) and consequently the beach that happens to be lodged before the mouth of the harbour, directly into the throat thereof. The south-eastern seas indeed are so short that they do not much affect the mouth of this harbour any way, but by the pier turning so much to the west it greatly facilitates the beach after it has got round its salient point to get along this flank, whose line of direction being overlapped by the eastern head, is thereby equally caught and retained, when the wind is more to the west than the S. S. W. direction of this flank; for it is very observable that the seas will wrap themselves round a head, and act with great power several points of the compass from the wind that causes them. Nothing therefore, as it seems to me, could have been formed more improperly with respect to the bringing of beach into the throat of the harbour, nor indeed, in all southerly winds, with respect to bringing in the seas into the harbour, had not this last effect been in some measure prevented by the jettee or tongue projected from the eastern pier at the inner entry into the harbour which catches them as they run along-side of the eastern pier.

I would therefore advise, by way of lessening as much as possible the quantity of beach that can get round and lodge between the pier heads, and as the first and most important work that can be done, to prolong or carry out the first mentioned line of the head in its direction S. S. E. and that far enough to come into a S. S. W. direction from the extremity of the east head, which will be done by extending this face about 90 feet, as shewn in the plan hereto annexed, and then returning the outside so as to fall in with the salient points of the present pier. The additional work will form a sort of triangle, whose base will be principally formed by the present S. W. flank, and whose projection forward towards the S. E. in a line perpendicular to the base, will be but little above 60 feet further out than at present. By this construction all the good that arises from the shape of the present pier head, in regard to locking in the beach, will be retained; and as all winds that are farther out than S. S. W. (that is than south of the true meridian,) which include all those which are the most prejudicial, will meet the outface of the new work obliquely, they will rather tend to send the seas and beach to seaward, than to bring them round the head into the throat of the harbour; and as to all those winds that are eastward of the S. S. W. they

are

are found to be productive of no ill effect upon this harbour. The intent then of this projection is not by way of lengthening the head, so as to make it lock in or retain a greater quantity of beach, but by making it to overlap the eastern head sufficiently, to cause the beach brought coastwise by the great seas at W. S. W. to shoot beyond the eastern head, before it is brought up again upon the shore, and by giving it such a shape as shall also tend in the most effectual manner possible to make the beach drive out to sea till it has passed the harbour's mouth.

I am sensible at the same time, that neither this nor any other shape or prolongation of the piers will totally prevent the beach from coming into the harbour's mouth; for though this reasoning would hold good if the waves of the sea were reflected from fixed objects, like light from polished surfaces; yet the seas, as already observed, so wrap round the surfaces of bodies that oppose them, that they will in some degree go round even while they come into an opposite direction. They may therefore more aptly be compared to the nature of sound than light; yet as the gross and violence of the action is spent according to the angles and directions wherewith they first strike, the main force or stress of the action will conform to those laws; and hence (as it may be expected) if two thirds of the whole quantity of the beach that now would lodge itself in the harbour's mouth is diverted so as to pass by it without entering, it will follow that the third part will not be of one sixth of the evil consequence and inconvenience to the harbour; and that rendered more easily and readily to be removed by the action of the sluices.

It is perhaps impossible to make a compleat artificial harbour, for what improves it in one sense will often be of detriment in another; for this reason the main drift and purpose thereof is to be principally attended to, and when that is done to as great an advantage as may be, that harbour may be said to be in the most perfect state its situation is capable of. I am therefore aware that this addition to the head here proposed may meet with some objection from seamen; for it may be argued that the present westerly turn of the head admits ships coming from the westward with a scant wind at N. N. W. more easily and readily to shoot up into the wind and get between the heads, (from whence they warp into the harbour) with less risque of over shooting their port, than if this prolongation were to take place. To this I answer, that as there is frequently a bank of beach lodged high against the pier in the very place where the new work is proposed (ready to be driven in between the heads by the first shift of wind more southerly), this will either by the reality or the fear thereof prevent vessels from making the turn of the west head sooner, especially if they have no pilot on board, than if this vacancy were occupied with a solid pier, which they will always have the advantage of seeing above water, and against which, from its shape

shape and position, no material quantity of beach can ever lodge. I must also observe that if a ship is coming up the channel intending for this port, she always has either the wind at large, so that she can keep a proper offing and alter her course proper to run right into port, or else it is an off shore wind, wherein if she pleases she may drop an anchor before the harbour's mouth and afterwards warp in.

2dly. It may also be alleged that the present face of the pier head is sometimes useful for ships to lie along side; in order to cast off when the wind is fair to go up or down channel, and with such a wind as does not enable her to *fail* out of port: but it may be observed in answer that besides the objection, that when a bank of beach is lodged here no use can be made of this side of the pier for this purpose; it may be further observed that for all ships going easterly, the proposed east face will be better adapted in southerly winds than the present; and for ships going westerly, a transport buoy fixed at a proper distance to south-eastward of the harbour's mouth, would answer far better for this purpose than the present pier, and that, even independently of such a buoy, there are some winds which the proposed face would answer to better for ships to cast off from to proceed westerly than the present. I am told that such a buoy has been formerly fixed and maintained, and it seems very adviseable that it should be replaced*.

This in my opinion is the whole and most effectual means that can be used to prevent as much as possible the beach from getting into the harbour's mouth. I come now to consider the most effectual method of removing what does come in.

In the time of spring tides, as has been already observed, there is no difficulty; and in regard to neap tides, as the quantity that can get in will after the execution of the proposed head be far less than at present, it may with more ease be removed, even with the present power; but as that does not seem sufficient to be absolutely depended upon, I shall now shew what is in my opinion the most effectual way to improve it.

On Thursday morning the 23d of February, being the third day after the full moon, a full head of water was penned in and the turn-water next the east pier head set, I observed the state of the beach about and between the heads, (which indeed were tolerably clear) before the sluices were played at low water, in order that I might see the operation thereof. I observed that the gates of the sluices were five minutes in drawing, and that the water

* The prolongation of the west head and fixing a transport buoy, I find was adopted by Captain Perry in his report on this harbour 1718.

took up the same time in getting down from the sluices to the pier heads, that it was five minutes more in getting to its full strength, which continued for about half an hour; but after that, though it continued a quarter of an hour longer, the effect was inconsiderable. After the operation I observed that wherever the beach had laid in the way of the water, it was greatly reduced and carried so far without the heads that the westerly seas would infallibly carry it beyond the east head, and prevent its returning into the harbour.

I observed that before the sluices were drawn there did not appear to be above six or eight inches of fall from the apron of the outmost turnwater to the sea, and about an equal declivity from the stone apron of the great gates to the said turnwater apron, so that from the stone apron of the great gates to the sea the fall could not much exceed a foot, or at most eighteen inches of declivity, but will be variable according as the tide ebbs more out; I only beg leave to observe that this will be the ordinary state of it in spring tides, as the present ones were said to be of a middling kind. I observed further that the water from the sluices when in their full power scarcely overtopped the turnwaters, which appeared to be about three feet and a half high, so that the fall of the water's surface from the turnwater to the sea was scarcely more than four feet; and yet in this state the sluices are capable of keeping the harbour clear. I was informed that at neap tides sometimes the water will ebb down to the stone apron of the great gates, but ordinarily so as to leave about twenty inches upon it, scarcely ever more than two feet, if it be not penned by beach cast into the harbour's mouth. Hence it appears that at neap tides there is not above three feet more depth of water at the harbour's mouth than at spring tides, and consequently by the power of water that will overtop the sea water at neap tides as much as it now does at spring tides, the harbour's mouth might be cleared as effectually at neap as it is now at spring tides, and this would be effected if the capacities of the sluices were doubled; for the same descent of the surface would produce the same velocity and effect upon the bottom, and being confined to the same breadth a double quantity of water would produce a double height, which would then have as good or a better fall into the sea at neap tides, than it now has at spring tides.

It is true that being discharged in double quantity it would be spent in half the time, so that instead of lasting half an hour in full vigour, it would last only a quarter; but as a much greater body and weight of water will act at once a considerable effect must be produced, so as greatly to relieve the harbour's mouth, which though not made perfectly clear till the approach of spring tides, would, in conjunction with the relief that is to be expected from the proposed addition to the west head, prevent its ever being barred up at neap tides or prevent its use to all middling vessels; for even a single discharge of the sluices

fluices with the power I have mentioned, would in a manner remove the gross of any obstruction that then could happen.

I was informed that in summer they can generally gather a full basin and pent of water in four days, and one in a week in the very driest seasons and shortest tides; if so the pent might always be kept full against neap tides, so as to fill the basin or nearly so on shutting in the first tide that shall happen after the approach of any emergence; I say the approach of any emergence, for whenever it comes to blow at such points as are found by experience to bring in the beach, it is not necessary to wait the event but to prepare immediately to get a full head of water.

There are two ways by which the capacity of the fluices may be augmented. One is by building a new tunnel at each end of the present stone wall. The width of the present tunnels or archways for the draw gates is twelve feet, but as I am perfectly clear that the advantage of the fluices does not so much depend upon the length of time they play, as upon the great body that can be at once discharged; I would advise that the new tunnels would be fifteen feet wide each, and not be shut by draw gates but by turning gates, by which the water can be instantly discharged without loss of time or addition of hands. The execution of this method will require the most time and expense, but when done will be the most durable and require the least repairs.

The second method is by placing turning gates in the great gates, which can be discharged and will operate like the former, and answer the end in all respects the same: the only objection to this method, is, that folding gates made with turning gates encased are not only more expensive to construct, but less durable than folding gates made plain and whole; otherwise the business will be done in this way at far less expense and in much less time than with stone tunnels, especially as the great gates having been lately renewed may be made still to serve by having turning gates adapted to them.

As I do not know of any turning gates encased in folding gates in England, it perhaps may be doubted whether the thing be practicable, but for their information I beg leave to mention that this very thing is done and practised with success, not only at the Briel but in the great gates of the sluice of Helveot in Holland, and made use of for scouring the outward harbour and pier heads, and that it was formerly done in the great sluice of Mardick near Dunkirk, before it was demolished by treaty.

As

As therefore this method can be put in practice in a shorter time, and at a less expense, I would the rather advise it at present to be adopted, that when the good effects thereof are seen, the larger and more durable work in stone may be doing while the first pair of gates are in wear, which may afterwards be changed for those of the present construction when the others are executed.

The sluice of Helveot is forty-eight feet wide: the gates, which I saw the year 1755, by a date upon them, appeared to have been constructed in the year 1722, so that they had been in thirty-three years, and were then in perfect good repair; they had however originally been exceedingly well constructed and very strong. I happened to have an opportunity of seeing the operation of this sluice, which I well remember was far beyond the present ones at Dover, though the turning gates encased in the great gates were the only apertures they had for discharging the water from the basin, which, according to my idea, is much less than the Dover basin and pent together; the whole operation was in a manner over in a quarter of an hour.

The addition to the west head I would advise to be of stone, which will not only be more durable and in the end cheaper than wood, but will probably shew the way of rebuilding the present piers with stone as they may occasionally want it, which it is to be wished had been done at first.

The outside of the new work I would propose to be constructed of Portland blocks, but the inside may be done with the large rough stones that are brought from Folkestone, such as are used for filling the present piers. I would however advise, that to the height of six or eight feet, the south face of the proposed addition may be done with Cornish moor stone, as the expense will not create any material difference upon the whole, and its hardness will prevent its being affected by the beach rubbing against it.

It would be beside the present purpose to make out designs for the execution of the proposed works, till the execution shall be resolved upon; and yet without this it is not possible to come to any complete estimate: however by way of giving some general idea of the expense, I suppose the stone head may be done for the sum of £7,500. and the gates made upon the plan I have mentioned, for the sum of £1,500, including an addition to the apron to prevent the action of the water from gulling the bottom.

Either the increasing the water way or the addition to the pier, I expect will be of great service to the port, and as one is chiefly masonry and the other carpentry, if proper funds can

VOL. III.

U

can be raised they may be both carried on together; but if they are to be carried on separately, I look upon the alteration of the head as of the most immediate consequence and importance.

It may be proper to suggest that when the port of Dover is by the means above specified put upon the best footing its situation is capable of (that is, according to the best of my judgement) I apprehend it will be very eligible to be more frequently used by the king's sloops and lesser frigates, and therefore that for fitting them out it would be very practicable to build a dock in the place now called the Paradise Pent, which is in a manner a waste piece of ground, and where the excavation for the purpose is in a great measure ready; this having been in ancient times, as I understand, a very material part of the harbour.

Auslhorpe,
17th June 1769.

J. SMEATON.

OPERATION of the Turning Gate Sluices for Dover Harbour.

When the gate is to be shut for penning in a head of water, the rope from the crab is to be hooked to the downstream side of the gate, and by that means brought close to its bearings. When the water comes against it the other half of the gate will be supported by its threshold and cheek, in the same manner that common sluice gates generally are, but as the part of the gate that lies downstream when open, receives no support from either, in order to give it that support, a triangular frame called a Valet, turning upon two gudgeons is brought round, and acting as a lever, its turning post is made to bear hard against the clapping post of the gate, and thereby firmly supports it, and presses it upward against its cheek, which it would otherwise be inclined to depart from; and in order to make it the more tight, an eye upon the end of the diagonal lever of the valet is brought towards an eye upon the fixed beam by a luff tackle, and in that situation is lashed by several turns of a cord round the pummels; this done, the crab rope is to be hooked, and then the gate is set for penning in a head of water.

In

In order to discharge it, the lashing is to be cut, and a part of the gate being then unsupported, will throw open the valet, and in part open itself, but to set it right square the crab is to be made use of, and will be stopped in its proper position by the counter thresholds. The water then runs through in a full bore, and by its superior accumulation in the exterior harbours, will act in proportion more strongly upon the beach at the entry of the pier heads.

N. B. By giving the greater side of the gate still more advantage, it might be made to open wholly of itself, but as its operation would then proceed with violence, it is judged more safe to have recourse to two or three turns of the crab, which a small power will serve, the gate being nearly in equilibrio.

REMARKS.

According to my notes, the overfalls of the draw gates are about eighteen feet above the floor of the great gates. The floors of the turning gates are proposed to be one foot higher than that of the great gates, and being fifteen feet above the floor, they will pen in sixteen feet head of water, which will be fully sufficient for the neap tides, at which time these gates are principally supposed to be of use. When the full head of eighteen feet is to be penned; the water is to be stopped from going over betwixt the top of the turning and the cross beam, by flash boards, and as on all occasions the draw gates are to be first opened, by such time as that is done the head of water will be run off to the level of the turning gates which may then be discharged also: this being judged more safe than to raise the turning gates to the full height of eighteen feet.

Auslhorpe,
18th June 1771.

J. SMEATON.

U 2

ESTIMATE

ESTIMATE for erecting one of the Turning Gate Sluices, proposed at Dover Harbour,
of fifteen feet water way, by John Smeaton, Engineer.

	£	s.	d.
To erecting a dam of rabbetted piles so as to pen the water in the bason to its proper height, and defend the foundation of the sluice from the rise of the tides, the timber work being supposed to be completed in place at 5s. per foot	400	0	0
To a similar dam towards the outward harbour to pen out the neap tides from the foundation	400	0	0
To a horse engine for draining the water, complete	150	0	0
To piling machines and other utensils	200	0	0
Preparation	£ 1,150	■	0

N. B. The materials of the dams together with the engines and utensils will be equally serviceable in the second erection as the first, and at last sell as old stores.

The FLOOR.

	£	s.	d.
To 1008 feet of fir timber in bearing piles, supposed ten inches square, and eight feet long, preparing, shoeing, and driving included, at 4s. per cube foot	201	12	0
To the main fell of fir timber, framing, jogging, bolting, and laying down, containing 175 feet, at 5s.	43	15	0
To 648 feet of fir timber in the common fells, preparing, levelling the pile heads, and trenailing down, at 3s.	97	4	■
To 180 trenails of 1½ in., at 6d.	4	10	0
To 972 feet superficial of four inch plank piling of beach, elm, or fir, at 3s.	145	16	0
To 150 cube yards of chalk rubble, to be rammed under and between the fell timbers, at 3s.	22	10	0
To planking the floor, containing 1060 feet superficial of three inch fir plank to be lathed and put together with tar and hair, at 1s. 6d.	79	10	0
To forty-two feet of oak timber in threshold framing, laying down and bolting, at 6s.	12	12	0

IRON WORK.

To 8 cwt. of iron work in bolts, plates, &c. for the main fell and thresholds, at 6d. per lb.	22	8	0
To 12 cwt. of spikes for the pile planking and floor, at 36s.	21	12	0
Total of the floor	£ 651	9	0

The

The SUPERSTRUCTURE.

MASONRY.

	£	s.	d.
To 10,638 cube feet of Portland stone to be set in pozzelana * or terras mortar, at 3s. per cube foot, all work included	1,595	14	■
To 9,751 cube feet of rubble backing, the mortar to have a mixture of pozzelana equal to one-third of its proper quantity at 1s.	487	15	0
To an allowance of 3d. per foot, upon the area for dressing stones, for paving, letting in cramps, &c. containing 1,908	23	17	0

IRON WORK, &c.

	£	s.	d.
To iron work in cramps 3 cwt., at 4d. per lb.	5	12	0
To lead for fixing them, 3 cwt. at 2d. per lb.	2	16	0
To oil, &c.	0	10	0
Total of the superstructure	£ 2,116	4	0

The GATE, VALET, and CROSS BEAM.

CARPENTRY.

	£	s.	d.
To 138 feet of oak timber in the turning post and cross beam measured in square in place at 6s.	41	■	0
To 248 feet of oak timber in the ribs, clapping posts and valet measured in square, at 5s.	61	0	■
To 220 feet of two inch fir plank for planking the gates on both sides, at 6d.	5	10	0
To framing and fixing the above, and letting in the iron work, containing 423 feet solid, at 2s. 6d.	52	17	6

IRON WORK.

To one ton of cast iron in gudgeons, pots, and boxes, at 22s. per cwt.	22	0	0
To 28 cwt. of forged iron work, in plates, bolts, &c. at 6d. per lb.	78	8	0
To 2 cwt. of spikes for the planking, at 36s.	3	12	0
Total of the gate, valet, and cross beam	£ 265	15	6

* N. B. Pozzelana has been imported from Italy to different parts of Great Britain, at the price of 40s. per ton, containing about twenty-four bushels each, and preferable to the same quantity of terras.

The

The crab with ropes, blocks, and iron work complete	-	-	£	s.	d.
To drainage of the sluice while building, supposing the labour of four horses for six months, or 180 days, at 3s. per day each, with two drivers at 2s. per day each, in the whole 16s. per day	-	-	50	0	0
To 600 tons of Folkestone rubble stones of promiscuous sizes, for securing the apron of the sluice, at 6s. 6d.	-	-	144	0	0
	-	-	195	0	0

ABSTRACT.

The preparation	-	-	-	£	s.	d.
The floor	-	-	-	1,150	0	0
The superstructure	-	-	-	651	9	0
The gate, valet, and cross beam	-	-	-	2,116	4	0
The crab, ropes, &c.	-	-	-	265	15	6
Drainage of the sluice	-	-	-	50	0	0
Folkestone rubble for securing the apron	-	-	-	144	0	0
	-	-	-	195	0	0
Neat estimate	-	-	-	£ 4,572	8	6
Allow for unforeseen accidents and expenses, 10 per cent. upon the above	-	-	-	457	4	10
	-	-	-	£ 5,029	13	4

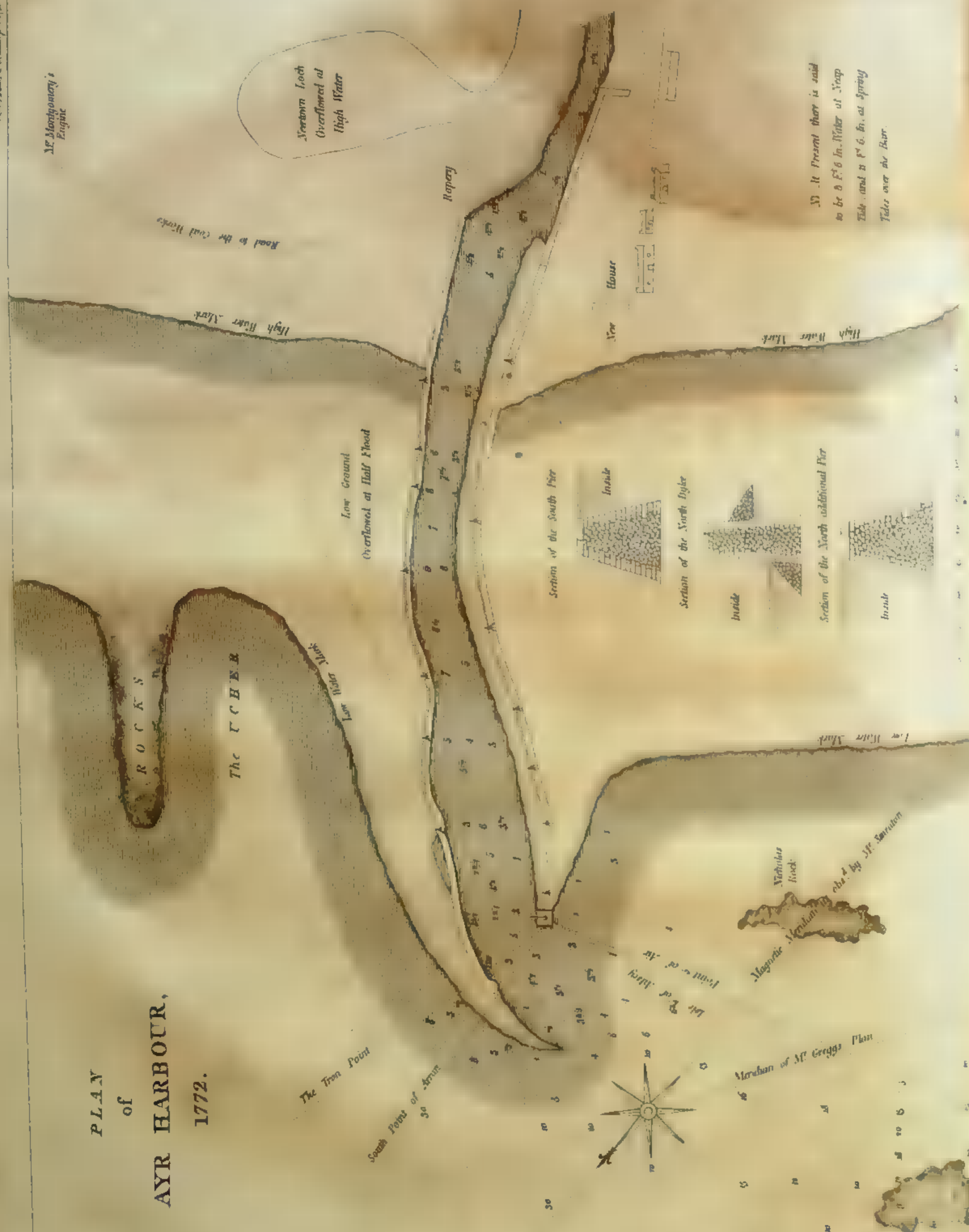
N.B. No salaries or gratuities to engineers or surveyors are supposed to be included in the above estimate.

Austhorpe,
18th June 1771:

J. SMEATON.

P.S. I cannot be answerable for prices, for want of a sufficient knowledge of particulars at Dover, but the prices herein set down are such as I think should rather exceed than fall short. But the quantities, being correctly estimated, the whole is capable of being corrected by any person well versed in the prices of work and materials at Dover.

PLAN
of
AYR HARBOUR,
1772.



[151]

AYR HARBOUR.

(See Plan, Plate 9.)

The REPORT of JOHN SMEATON, upon the Harbour of Ayr.

FROM a view taken the 2d September 1771, it appears to me that the harbour of Ayr which is near the mouth of the river Ayr, and which falling into the wide and open part of the Firth of Clyde, upon a *bar* with a drift sand, is by nature badly circumstanced for keeping open, having *namely* a bar before its mouth, as almost all others in like circumstances are more *or less* subject to; and were it not for the river Ayr, which being a river of middle size, and subject to great speats in rainy seasons, which drive the sands out to sea, that the surge with westerly and north westerly winds bring in and heap upon the entry of the harbour, it would be very speedily choaked up and destroyed. Seeing therefore, that the speats of the river Ayr are in a manner the only means by which the harbour is kept open, it follows, that to improve the same in depth of water, which is the present object, it is necessary to attend to these circumstances, by which the force of the land waters can act with the utmost advantage in driving off the sands, and to the forming and improving such artificial barriers as shall have the most direct tendency to prevent the effect of the winds in bringing it in.

Something for this purpose has been done many years since, in the erection of the north and south dykes or walls, to confine the channel of the river in passing the flat sands, but not having been effectually executed, the depth of water in the harbour is not so good as it might have been; however, though I have reason to suppose when what I have to propose is executed, that there will be a gaining of full three feet additional depth of water at a medium, yet as the action of the winds to bring in sands, and the floods to drive them out, are the two powers that are opposed to one another, but as at different times and in different degrees, it follows that from the nature and operation of such inconstant forces there will always be times when the depth of water will be alternately greater and less.

The principal fault of the present dykes is their lowness, which being in a great measure covered at half flood, the speats are left unconfined from half flood to half ebb, whereby a material part of the power of the speats to scour is lost. Another material thing, is, that the

the south dyke being so low, that the seas find a passage over a great part of it, even at one quarter of flood; and the sands appearing to drive coastways from the S. W. to the N. E. by the westerly winds, the south dyke does not prevent the sands from being washed over it into the channel of the harbour, and which must then remain till the speats come to drive it out again. Lastly as the north-west and northerly winds act very powerfully on the mouth of the harbour, and the seas having a long fetch from the north down the firth of Clyde, they have power enough to prevent the larger gravel that comes down the river from getting out to sea, and thereby form the north bank extending from the north pier to the north-west, so as to bar up the harbour entirely to the north, the bank being dry at low water, and forcing the land waters to take their course to the westward: when a number of large speats happen, this bank almost directly opposing the land current, the bank is driven out more to the northward, so as to admit the vessels to steer in from the N. W.; but by a series of northerly winds without freshes, this bank is brought closer in, so as to oblige the vessels to steer in from the W. by N. as it was when I saw it, and sometimes from the west, and as this is the direction nearly of the two present heads, vessels then going in with a scant wind, are apt to be driven upon the north pier.

The most obvious remedy for those evils in part is to build up both the south and north dykes up to high water mark, for by this alone a considerable part of the obstructions will be removed; the sands will be prevented from driving into the harbour from the south west and the speats and land floods being confined, they will act more powerfully upon the bottom, and therefore being preserved in one column till they pass the heads they will act more forcibly upon the north bank to drive it off, and by that means not only keep the Channel more to the north but also make deeper water over the Bar; it is not a matter of calculation to determine what additional depth will be hereby gained, but I should expect it to be not less than eighteen inches over the Bar.

The shape and position of the north bank shews how the powers of nature are balanced; and though it may be very desirable to force a passage right through the bank directly out to sea, yet this seems too great a thing to be attempted. I apprehend it better to conform to nature than attempt to force her, as I take it for granted it will be more desirable to have a good deep passage out at N. West than an indifferent and obstructed one at N. or N. N. West.

It was with a view doubtless of keeping the channel to the North, that the south dyke was carried out so much further than the north, but yet it has not this effect; for though the seas have power enough to keep up the north bank of such a height as to prevent vessels

vessels going over it, yet being covered at young flood, it is so low that speats find their way over it in so great a breadth, as not to be able effectually to remove it; by this means a great part of the force of the land waters is spent in a fruitless effort to do what they can never sufficiently accomplish to answer any good purpose; I therefore propose to turn their whole effect to such a quarter by co-operating with nature they may act with full advantage, and thereby maintain the greatest depth of water possible in such a situation.

This will be done by lengthening out the north dyke or pier towards the west, as shewn in the plan, by which means the whole force of the back-water being spent in a N. W. direction, and the north bank prevented from being driven in by the seas into the harbour, I expect there will be more water over the bar than at present by at least three feet, and the direction in and out permanent to the best situation it is at present capable of.

The only objection I see to this prolongation of the north head, is that the N. West sea will fall right into the mouth, and carry a swell into the harbour; but as this harbour by the south point of the mull of Cantire and the north of Ireland is in fact land locked from every quarter, there never can be any very violent surges such as coasts open to the ocean are subject to; and the quay is so far upwards from the mouth, that what comes in will be in a manner spent before it comes to the place where the ships lie. However, I apprehend this will be the least of those evils the harbour is subject to; and in all artificial harbours, we have only the choice of the least evil.

The present irregularity of the north and south dykes makes it very difficult to form an estimate of the expense of completing them; but taking it for granted that stone can be procured at the same price as that employed for the new coal quay, the best I can make will be as follows.

ESTIMATE for the Harbour of Ayr.

	£	s.	d.
The North Pier being supposed 16½ chains long = 363 yards; and supposing half of this to want raising at a medium 4 feet high and 5 feet thick, will contain 403 cube yards at 7s.	141	1	0
To rubble for footing the present dyke, viz. 2 yards per yard running for the harbour side, and 1 yard per yard running for the outside, viz. for the whole length 1089 yards at 6s.	326	14	0
	To		

the south dyke being so low, that the seas find a passage over a great part of it, even at one quarter of flood; and the sands appearing to drive coastways from the S. W. to the N. E. by the westerly winds, the south dyke does not prevent the sands from being washed over it into the channel of the harbour, and which must then remain till the speats come to drive it out again. Lastly as the north-west and northerly winds act very powerfully on the mouth of the harbour, and the seas having a long fetch from the north down the firth of Clyde, they have power enough to prevent the larger gravel that comes down the river from getting out to sea, and thereby form the north bank extending from the north pier to the north-west, so as to bar up the harbour entirely to the north, the bank being dry at low water, and forcing the land waters to take their course to the westward: when a number of large speats happen, this bank almost directly opposing the land current, the bank is driven out more to the northward, so as to admit the vessels to steer in from the N. W.; but by a series of northerly winds without freshes, this bank is brought closer in, so as to oblige the vessels to steer in from the W. by N. as it was when I saw it, and sometimes from the west, and as this is the direction nearly of the two present heads, vessels then going in with a scant wind, are apt to be driven upon the north pier.

The most obvious remedy for those evils in part is to build up both the south and north dykes up to high water mark, for by this alone a considerable part of the obstructions will be removed; the sands will be prevented from driving into the harbour from the south west and the speats and land floods being confined, they will act more powerfully upon the bottom, and therefore being preserved in one column till they pass the heads they will act more forcibly upon the north bank to drive it off, and by that means not only keep the Channel more to the north but also make deeper water over the Bar; it is not a matter of calculation to determine what additional depth will be hereby gained, but I should expect it to be not less than eighteen inches over the Bar.

The shape and position of the north bank shews how the powers of nature are balanced; and though it may be very desirable to force a passage right through the bank directly out to sea, yet this seems too great a thing to be attempted. I apprehend it better to conform to nature than attempt to force her, as I take it for granted it will be more desirable to have a good deep passage out at N. West than an indifferent and obstructed one at N. or N. N. West.

It was with a view doubtless of keeping the channel to the North, that the south dyke was carried out so much further than the north, but yet it has not this effect; for though the seas have power enough to keep up the north bank of such a height as to prevent vessels

vessels going over it, yet being covered at young flood, it is so low that speats find their way over it in so great a breadth, not to be able effectually to remove it; by this means a great part of the force of the land waters is spent in a fruitless effort to do what they can never sufficiently accomplish to answer any good purpose; I therefore propose to turn their whole effect to such a quarter as by co-operating with nature they may act with full advantage, and thereby maintain the greatest depth of water possible in such a situation.

This will be done by lengthening out the north dyke or pier towards the west, as shewn in the plan, by which means the whole force of the back-water being spent in a N. W. direction, and the north bank prevented from being driven in by the seas into the harbour, I expect there will be more water over the bar than at present by at least three feet, and the direction in and out permanent to the best situation it is at present capable of.

The only objection I see to this prolongation of the north head, is that the N. West seas will fall right into the mouth, and carry a swell into the harbour; but as this harbour by the south point of the mull of Cantire and the north of Ireland is in fact land locked from every quarter, there never can be any very violent surges such as coasts open to the ocean are subject to; and the quay is so far upwards from the mouth, that what comes in will be in a manner spent before it comes to the place where the ships lie. However, I apprehend this will be the least of those evils the harbour is subject to; and in all artificial harbours, we have only the choice of the least evil.

The present irregularity of the north and south dykes makes it very difficult to form an estimate of the expense of completing them; but taking it for granted that stone can be procured at the same price as that employed for the new coal quay, the best I can make will be as follows.

ESTIMATE for the Harbour of Ayr.

	£	s.	d.
The North Pier being supposed 16½ chains long = 363 yards; and supposing half of this to want raising at a medium 4 feet high and 5 feet thick, will contain 403 cube yards at 7s.	141	1	0
To rubble for footing the present dyke, viz. 2 yards per yard running for the harbour side, and 1 yard per yard running for the outside, viz. for the whole length 1089 yards at 6s.	326	14	0
	To		

To making up the south dyke, being supposed 19 chains or 428 yards long, being supposed 12 feet thick at base, 5 feet at top and 10 feet high, will contain 4042 yards at 7s.	1,414 7 ■
To lengthening the north dyke by an additional pier of 5 chains long or 110 yards, to be at a medium 15 feet base, 5 feet top, and 15 feet high, will contain 1833 yards at 7s.	641 11 0
Neat estimate	£ 2,523 13 0
Allow for contingencies at 10 per cent	252 7 4
Total	£ 2,776 ■ 4

N. B. The prices of the above estimate are formed upon the expense to me delivered of building the new coal quay on the north side of the river, deducting the expense of timber and lime, which will here be unnecessary. The quantities in respect to length are taken from the plans of Mr. Gregg to me delivered, upon a supposition of its being laid down by a scale of 3 chains to 2 inches,* there being no scale annexed to the plan; but if I happen to have taken my measures from a wrong scale, the expense must be increased or diminished in proportion as the real measures turn out greater or less than I have supposed them.

Austhorpe,
22d January 1772.

J. SMEATON.

* This is commonly marked fifteen among the plotting scales.

HULL QUAYS.

REPORT on projected Quays at Hull, 17th April 1773.

Mr. Smeaton is desired to give his opinion upon the following question, viz.

SUPPOSING a platform or quay be advanced to the distance of fifteen feet beyond the fronts of the staiths or warehouses on the west side of the river Hull, within the town of Kingston upon Hull, from Hickson's staith south of Walton's ship yard north, to be supported upon piles, leaving the course of the river open underneath the said advanced wharf, or otherwise making the same up solid within the said advanced space:—
Quære, whether this will have any, or what effect, upon the drainage of the carse lands and low grounds that discharge their water into the river Hull, above the north bridge of the town; and also whether it will have any, and what effect, upon the wharfing or jetties on the east side of the river opposite to the said advanced wharfs; on supposition also that docks for the reception of vessels are to be constructed in the town's ditches on the north west side?

The Answer of John Smeaton, Engineer.

Having carefully viewed the river Hull from the Holderness sluice, a little above the north bridge to the garrison jetty; and having perused the several reports of Messrs. Mylne and Robson, of Mr. Grundy and of Mr. Wooler, respectively; having also made diligent enquiries of those whom I esteemed best able to inform me; I beg leave first to lay down the following facts:—

1st. That when it is low water in the river Humber, the river Hull in the greatest land floods does not fill the channel thereof (within the space above mentioned) so high as half-tide mark, and then goes off with great rapidity.

2dly. That when it is high water in the Humber, the greatest land floods make a current of but very moderate velocity.

3dly. That the sea doors of Holderness sluice continue shut several hours during the time of high water, even in wet seasons.

4thly. That

4thly. That the frontages of matter formed before the staiths and warehouses specified in the above question, are at a medium uncovered to the breadth of fifteen feet and upwards at half tide.

N. B. As there was a considerable fresh in the river, from preceding rains, on my view thereof, as well as a considerable discharge from the Holderness drain, the information whereon the three first articles were established was in a great measure confirmed by my own observation, and the last occurred upon my own view.

From the above I infer, that by the great activity in the river in the above space, (which from former observations I make to be about four feet), notwithstanding the many obstructions therein, as all the natural flood waters are carried off in the bed of the river, without swelling it so high as the half or middle tide mark, the greatest obstruction to their getting away when above that level is the opposition of the tide of flood from the Humber, which alone causes them to rise above that level; and though the several impediments mentioned in the said several reports, undoubtedly contribute something; yet these impediments altogether, when the surface of the river is above half tide mark, are small in proportion to the opposition of the Humber's tide.

2dly. That the drainage of the Holderness and other carrs must necessarily be carried on principally while the river Hull is under the half tide mark, that is from half ebb to half flood; and consequently, as during this time a projection of fifteen feet from the fronts of the staiths above mentioned, would rest on ground that in general would be uncovered by the water; the drainages above mentioned would suffer no sensible change, whether the said projected staiths are built up hollow on piles, or solid with walls.

3dly. Since the velocity of the water of the river Hull, within the space above mentioned, is very much slower when above the level of half tide than when below it; and since it is a known fact, that the scouring of rivers by land floods chiefly takes place when they run over the beds of the rivers at low water, it follows that the projection aforesaid, whether solid or otherwise, will make no alteration in the action of the river upon the wharfing or jetees on the east side.

I am therefore of opinion, that the proposed projection of 15 feet cannot be of detriment to either the drainage of the low grounds into the river Hull, nor to the wharfing or jetees on the east side of the river, even if made solid, but if built on piles, this appears to me

to

take away all colour of objection; and in case a wet dock for the reception of ships and vessels be made in the town's ditches on the north west side of the town, as this will proportionably diminish the number of vessels that now lie as obstructions in the stream of the river at low water, the obstructions upon the whole must be lessened, especially at the time of low water, when every impediment to the free course of the river is of the most consequence to the drainage and security of the said wharfs and jetees.

Hull,
17th April 1773.

J. SMEATON.

An APPENDIX to the REPORT of JOHN SMEATON Engineer, upon the proposed Quays and Docks at Hull, 17th April 1773.

BEING called upon this business without previous notice, and being through want of time obliged to deliver my opinion with more brevity and less explanation than I otherwise should have done; being also lately called to meet Mr. Grundy at Hull, who was invited to give his opinion upon a proposition of the same nature, as that which formed the subject of my report above mentioned; I have on this occasion had a further opportunity of extending my observations, and conversing with Mr. Grundy upon the nature of the case; and having also the pleasure to find, that when the same proposition is stated to each of us, we do not materially differ in our conclusions; yet as each of us has proceeded in his separate report, to form his opinion by a mode of reasoning somewhat different; we find it will be more easy to ourselves, and more satisfactory to our employers and all concerned, to deliver what we have further to say, according to our own words and conceptions: And I find no reason now to deviate from any material fact or opinion contained in my said report of the 17th April last; what I now offer I shall consider as an appendix to that report, and in further explanation and confirmation of the conclusions therein contained.

In Mr. Grundy's report of the 14th October 1773, he has given the admeasurements of Hull harbour or haven from the outlet thereof at the garrison jettee to the north bridge, at thirteen different places; which dimensions, as I doubt not of their having been taken with all due care and fidelity, I beg leave to refer thereto, and found myself thereupon. The first and the two last of these admeasurements lying without the limits of the proposed undertaking, I put on that account out of the investigation of a mean section of the harbour.

I think

I think it right, however, to take the several capacities within the limits above mentioned altogether, and draw the medium from the whole; and not from the most contracted places only; because the several parts can obstruct more or less, only in proportion to the contraction along each space respectively, the sum of all the obstructions being made up of the sum of all the parts taken separately.

The measures opposite the three interior jetees, contained in numbers 3, 5, & 7, being contractions of a peculiar kind, without appearance of real utility, I class them by themselves, and then taking a mean of all the remainder, viz. 2, 4, 6, 8, 9, 10, & 11, I find that by proceeding to draw a mean section therefrom, in a manner similar to that whereby Mr. Grundy has obtained a mean section of the narrowest places in his report.

				feet.	inches.
The mean high water line will be	-	-	-	195	6
The low water	-	-	-	112	6
The depth at low water	-	-	-	5	9
And the total area of the section	-	-	-	4100	sq. ft.

Proceeding in like manner with the three sets of dimensions at the said three jetees, the mean dimensions will be, viz.

Mean width at high water	-	-	-	-	168	6
Ditto at low water	.	-	-	-	102	9
Mean depth	-	-	-	.	5	3
Mean area of the section	-	-	-	-	3573	

Now, as these things at present stand, those jetees have their share in obstructing the current of the water; and supposing their influence equally extensive as the former, (which is more than there is need to allow), the mean section of the harbour as it now stands will be the mean of the areas of those two mean sections.

The whole will stand thus:—

	feet.
The mean or average section of the harbour, exclusive of the jetees	4100
The mean or average section of ditto at the jetees	3573
The difference	527
The mean of the average	3836

So

So that 3836 feet I consider as the mean section of the harbour, — it now stands, when clear of shipping; and if from this we deduct what Mr. Grundy has deducted for the mean or average sections of four ships lying abreast in this harbour, viz. 448 feet, we shall then have a neat mean section, with the shipping, viz.

					feet
Neat section of the haven, clear of ships	-	-	-	-	3836
It at a medium for shipping	-	-	-	-	448
Remains clear water way, with the shipping	-	-	-	-	3388

The section of the proposed project will, as I compute it, occupy $152\frac{1}{2}$ feet part of the whole section, with the . . .

Deducting from the above area	-	-	-	-	3388
The whole section of the quay	-	-	-	-	152 6.
There will still remain after the quay is made, clear	-	-	-	-	3235 6

Mr. Grundy has in his report also given the admeasurement of the river Hull in different places above Hull bridge, from whence and from the before cited admeasurements it appears, that the said clear section of $3235\frac{1}{2}$ feet, mean section of the river before the proposed quay, supposing all impediments to remain, is yet larger than any clear section of which the admeasurement is given above the said proposed quay; the largest of them all, viz. below Holdernefs new clough, which is below the outfall of all the drainages, Mr. Grundy has now accurately computed to be 2969 feet, that is $266\frac{1}{2}$ feet less than the mean section opposite the projected quays. If therefore the said largest section of 2969 feet taken below all the drainages, is esteemed sufficient, no detriment can be apprehended from the proposed quay, as it leaves a clear water way of $266\frac{1}{2}$ feet more than sufficient; but as I apprehend this argument, though just, is inconclusive, upon the principle of my own reasoning, viz. that every section of a river is more or less an impediment to the currency of water; so that as impediments they only differ in quantity, as the section is relatively greater or less, the sum of all the impediments being the sum of all the particular parts as above stated; we will therefore now examine the matter as to the question.

At the time of high water of a high spring tide with a great land flood in the river, when it is supposed the river rises to the height of twenty-two feet above the ordinary low water

water line, in which state the sections above referred to are stated by Mr. Grundy and myself; it is allowed that in this state the quay will occupy $152\frac{1}{2}$ feet of the section, being at a medium $\frac{1}{3}$ d part of the whole nearly; but at the time of high water even in the greatest land floods, the water being then in Hull haven nearly stagnant, it cannot in that state be any impediment at all; for were there a sheet of piling across the river, while the water continued stagnant, it could have no effect. At low water also, as the greatest land flood would be below the face of the quay, as the ground now lies, it then can be no impediment; the impediment, if any, must therefore be the greatest at some point between high water and the time that the tide leaves the face of the quay, which in the ordinary state of the river will be at or very soon after half tide; and from a computation that I have made for this purpose, in which every circumstance is exaggerated in disfavour of the quay, it can never have the effect of causing the water to swell at the head of the quays above $\frac{1}{2}$ an inch; and as this will be when the water has subsided below high water about 7 feet, so that the swell of $\frac{1}{2}$ an inch at that time cannot be supposed to have any effect upon the running off of the water in the superior parts of the river, or so minute a one that it escapes calculation to say what it is.

With respect to the discharge of the land flood waters, as affecting the barrier banks of the adjacent lands, it is evident that the pinch of the whole affair is at high water, when it has been shewn that the water being stagnant, the impediment is reduced to nothing: again, as the internal drainage sluices must do the greatest part of their business after the water has left the face of the quay, its impediment to them is reduced to nothing also; or to so very minute a quantity as to justify the opinion I have already given in my report of the 17th of April last, that the proposition of 15 feet cannot be of detriment to the drainage of the low grounds into the river Hull, or to the wharings or jetees on the east side of the river, even if made solid.

However, as it may be expected by the proprietors of land, and desired by the promoters of this undertaking, that every cause of apprehension, however minute, should be intirely removed or fully compensated, it will follow, that if an addition of water may be made equivalent to $152\frac{1}{2}$ feet, that this will at all events counterbalance the supposed obstructions; and if the said addition of water-way is of such a nature as to operate during the whole time of tide, or when the water is at a lower level than the said quays can impede, instead of a detriment this must be considered as a benefit.

Now, if but a single row of vessels that now lie in the harbour are supposed to be moved into the wet dock, and supposing them at a medium to occupy an area equal to 20 feet wide, and

and 8 feet deep, this produces 160 feet, which will equally operate at low water as at high; and as it is probable that the dock will entertain as many ships as will amount to a double and even a treble tier in the harbour, it will follow that the circumstance alone of transferring a part of the shipping to the dock, will be a most full and ample compensation for any impediment that can be supposed to arise from the projection of the quays, even if they were made greater than now intended.

A further advantage will probably arise from the removal of part of the matter before the face of the quays, that according to the present section now lies there; for as the ground is too steep for sea vessels to lie upon, it will certainly be the interest of the proprietors to remove it, in order that large vessels may load at the quay side; this will undoubtedly be gradually done, and will add to the section of the River towards the bottom, where one foot will be of more service than two near the top.

It is also to be remarked, that the difference of the mean section of the haven at the jetees and clear of them is no less than 527 feet, which is a quantity above three times greater than the supposed addition by the quays. It appears to me that those jetees are of no use, but on the contrary an impediment to the harbour, and that they may safely be taken away, or at least in the greatest part; and in case that can be effected without objection, I recommend it to be done, not only as an improvement to the harbour, but as of itself much more than an equivalent to any impediment that can be supposed to arise to the drainage from the quay.

The North Bridge is also another subject of improvement to the passage of the water; as upon tide of ebb from the multiplicity of timbers and obstructions there is a sensible fall here, and as the spaces between the cross rows of piles for supporting the dormant part of the bridge seem filled with stones or some kind of hard matter above the bottom of the river, those being removed will increase the section in this, now the most obstructed part.

As it seems necessary to make a communication with the Humber by draw gates from the wet docks, it will be practicable on extreme of floods to give passage to part of the waters of the river Hull that way; and upon emergencies there is no doubt but that this will be done, as it may be without detriment to the works; but as the Humber's tide at high water will equally oppose the passage of the waters by way of the dock as by way of the river, its motion will become so slow till it is got down to such level, as the gates can be no longer permitted to stand open, that in general its benefit to drainage can be so small

as not to demand, what on every account seems ineligible, viz. for the drainage to have command over the gates of the dock.

Upon the whole matter, having with Mr. Grundy carefully viewed and examined the state of the channel of the river between Fore Dyke and Hull Bridge at low water, I am of opinion that the obstructions in the channel of the river, particularly from Sculcoats Church to Hull Bridge, are so many and so great, that even if the river Hull from Hull Bridge to the Humber were dug as wide and as deep as the Humber itself, yet the drainage above Sculcoats would remain in nearly the same state as at present, till those impediments between Hull Bridge and Sculcoats were removed.

On examining also with Mr. Grundy the state of the bottom of the river between Hull Bridge and the South End, I find that the bottom of the river in every place, where the crowded shipping would permit a trial to be made, is composed of stones, and so hard compacted together, even in the middle of the river, that I did not find it practicable to pierce through it with a spit; this continued nearly the same till we got down opposite to the lowest of the three internal jetees, viz. Church Lane jetee, where in the middle of the river we first began to lose the stone, and below this (it being here the widest part of the harbour) we found the bottom a watry sand or silt, but yet stones on the wharfing on each side; from whence I conclude as before; that as the principal rapidity of tide of ebb will be when the water is below the face of the quays, that the eastern wharfs and jetees will be unaffected thereby; and that were the current much stronger than it is, it could make no impression upon the bottom of the river above Church Lane jetee, and below from the increase of width the current has a less tendency to make an impression, which tendency will be still prevented at the sides by the stones, in like manner as now that the three internal jetees by disturbing the regular set of the current are of disservice to the wharfing taken collectively; and if those jetees were removed, the stones will remain a better defence to the wharfing than in the present state.

J. SMEATON.

Ausborne,
18th December 1773.

HULL DOCK.

The REPORT of JOHN SMEATON and JOHN WOOLER, Engineers, upon the several Matters referred to their Consideration by WILLIAM WALKER, Esq. Chairman to the Commissioners of the Dock Company at Hull, by his Letter dated the 14th August instant.

HAVING carefully viewed the several matters referred to our consideration, so far as the present state of the works would admit, assisted by the information of Messrs. Holt, Turner, and Westerdale, we are of opinion as follows:

1st. Respecting those parts of the dock wall that are bilged out of their line, containing a length of 187 yards, or thereabouts, we are informed that the ground upon which they stand was not only more soft and spongy than any other parts of the dock, but that part being raised the latter end of a season which turned out rainy and wet, the masonry had never an opportunity of drying or setting to that degree of firmness that otherwise it would have done; and further, it appears to us by the report of Mr. Holt, as to the depth at which the whole was founded, videlicet, nearly even with the excavated bottom or basin of the dock, that the greatest cause of failure in this part was the not going to a sufficient depth below the general bottom in this soft stratum, so that the weight or resistance of matter before the foot of the wall might be a sufficient counterpoise to prevent the bottom from pressing forwards, and at the same time raising the ground before it. And as this appears to us to be a radical defect that cannot now admit of an adequate remedy, we see no certain method of preventing its going further, but that of taking down the whole length so bilged, and new founding it upon safer principles; but as this will be attended with a considerable loss of time, as well as of expense, we submit the following considerations to the Board:—

In the first place, we are willing to think that this derangement would not have happened, if the bottom and sides of the basin had been charged at that time with the weight of water intended to be pent therein; that is to say, had the dock been full of water. Secondly, we are of opinion, that the letting in the water, and keeping it pent up to its proper height, may afford the means of preventing this bilging from increasing, and in all probability would have the desired effect, were the dock always to remain so filled, or always with a considerable depth of water therein. Thirdly, that the greatest danger to be apprehended will be, when the water on account of any necessity or otherwise

wife is let out again, and as we cannot take upon us to say that this part of the wall would come down, or fail upon such a retreat of the water, we therefore cannot help recommending it to the Company, as every thing seems nearly ready for the trial, and nothing appears to us to forbid its being done, to put this matter to the test; for if any part of the wall should fail thereupon, it can be nearly as well rebuilt as now, and if it should thus bear the test, much time and expense will be saved. On this head therefore we beg leave to remark, that it would be proper to introduce the water so gradually, that it may for example be a week in filling, which may be done by plug holes cut through the frame dam. Afterwards to let the water remain at its full height for a fortnight at least, so as to give time to the earth that backs the walls to settle and consolidate, and then to let it out, not all in one tide, or so as the tide ebbs, but to bring the strain or stress upon the walls by degrees, allowing for example, to ebb out five or six feet the first day; the second to let it ebb out as low as the former; and after this, in the course of the recess of the tide to let off by the draw shuttles in the lock gates about three feet more; and thus day by day making the reduction by two and a half or two feet, till either the whole is let off that will go out, or that something shall appear to prohibit it; so managing the water discharged by the shuttles, as to take all the time in each tide possible, so as only to be drawn down to its intended gage by the time the tide has flowed nearly to the same height.

It is to be remarked, that in one place in this damaged wall, for about twenty feet in length, near the greatest swell of the western bilge (where the top of the wall is got out of the line two feet eight inches and a half), that the bottom part below the off-sets is further bilged and separated from the internal part; which part being of consequence weaker than the rest, we wish to recommend, by way of giving it an equal chance with the rest, that after the water is let in, and the frame dam removed, to form an artificial buttress against it, by dropping down Hazlecliff stones, brought into the dock by lighters, so as to form a slope against the wall higher than the set-off, this buttress by its weight will press equally against the wall, and prevent the bottom from rising; and should the whole by this means succeed, and these stones be found materially in the way, they may be afterwards removed, and the place otherwise secured in such a way as to be less liable to objection on that account; at any rate this place may be avoided without losing more than one birth by the quay side.

In regard to the rest of the wall round the dock, having the advantage of better ground, and being got up in better seasons, it appears to us to stand as it was built, without crack, or any apparent failure; we therefore apprehend and expect that it will prove sufficient, observing at the same time, that the whole is in our opinion defective in

not having the buttresses or counter-forts much nearer together; in consequence hereof, so great a stress lies upon the present ones, as in the bilging parts of the walls to have produced a thorough separation between the wall and buttress. There also appears a deficiency in the walls, in the omission of a proper quantity of throughs or large bond stones which ought to have been distributed throughout at due distances, in order to tie the brick-work properly together. We also beg leave to mention another disadvantage attending them, and that is, in not seating their bases or foundations a couple of feet or thereabouts, deeper in the ground, or in other words, below the general bottom or floor of the basin, in order to afford them the proper abutment or balance, when their weight joined to that of the earth they retain, comes to act with full force thereupon.

The second point referred to in the above letter is the rising of the floor of the lock in the middle, which we beg leave to observe arises from a natural cause, and will necessarily do so, more or less, according to the firmness of the ground upon which it is laid, and the strength of the timbers which compose it, joined with the perfect stability of the wing walls which form the lock. From the information of Mr. Holt, as to the scantling and distribution of the timbers employed therein, we are of opinion, that the floor is too slight for so massive a piece of work, which occasions it to spring more than it otherwise would have done. This spring or rising is in general about two inches at or near the threshold of the gate where the floor is double, but in the single floor of the chamber it is about three inches, but in the aftermost or stern-gate recesses, where the breadth or width of the floor is six feet greater, the spring or rising is four inches. We are therefore willing to hope the whole floor may remain or continue as it now is, and that no further inconvenience is to be apprehended therefrom, than what regards the facility of opening and shutting the gates. We had them tried, and found the north of the head gates, and south of the stern gates, move somewhat stiffly, yet as the letting in of the water will be likely to produce an easement, both by setting down the middle of the floor, and buoying up the gates, we cannot recommend an alteration till the whole is tried, and then it is possible several things may be better remedied than they can speculatively be foreseen. Respecting the walls of the lock they have the appearance of being well built; we however observe some small sets therein, which we impute to the want of strength in the foundation timbers.

Thirdly, to make the entry into the harbour, as easy and convenient as possible.

We have made a rough sketch of the ground adjacent to the entry, and apprehend, that to make all possible convenience the Dock Company should be possessed of Mr. Walton's ways or frontage before his wharfs into the river.

In answer to the fourth, regarding what is further to be done for the completion of the plan, we apprehend that the dock in its present state is wanting in some essential matters, the principal of which is the means of scouring it from the silt that will undoubtedly gather therein, by taking in the muddy tides from the Humber. Had the lock been made with gates pointed both ways, that is, towards the river as well as to the land, so as to shut out all such spring tides as would rise above the gage height of the constant water in the dock, much of this would have been excluded; also the depth of the dock being such as to retain four feet at low water, and being in breadth 255 feet, we are of opinion that no scowers from any practical reservoirs can take place, so as to clear the silt into the Hull, it therefore remains,* that by introducing the current of the river Hull at low water, (and particularly when there happens a fresh in the river at spring tides in the summer), to pass through the dock by means of a canal down towards the Humber, this clearance with the aid of men may be effected, which canal must be dug to a depth at least equal, or indeed rather of superior depth to that of the dock, with suitable sluices or locks thereon.

The four draw-gates now formed in the cross wall at Beverly Gates, amounting together to a breadth of fifteen feet only, we look upon as insufficient to let all the current from the river Hull pass through, that may be introduced to advantage, unless such a pen and fall be brought on at that place as would materially injure the declivity of the current in its passage through the length of the dock, and in consequence the strength of the scower. There being therefore a necessity for the removal of this wall, we would advise a sluice to be erected of equal depth with the present great lock, or indeed somewhat deeper, with a single pair of gates pointed towards the dock, and a draw bridge over it, for the Beverly roads.

At Myton Gate it will be sufficient to construct a bridge only of sufficient passage for the water, and at Hazel Gate a sluice of some kind, also of sufficient water passage, with a bridge over it. If this be made a navigable passage even for small vessels, some of them, such as the large keels from Thorn, &c. that cannot strike their masts, will render it proper that the bridges at Hazel and Myton Gates, should also be draw or moveable bridges, and we would recommend that the sluice at Hazel Gates, if made a navigable sluice or lock, should be constructed with double pairs of gates, pointed both to landwards and seawards; and we look upon it that a navigable sluice at Hazel Gates would be found very convenient for the following reasons:—

When a considerable trade comes to be established upon the basin, we apprehend it will be found very troublesome to open the great lock for the passage of keels, lighters, and

and small vessels, as well as reduce the water of the basin in neap tides. This defect may in some measure be supplied by constructing a proper lock for such vessels to pass in and out at the Hazel Gate, which if laid one foot deeper than low water at the Humber, will afford a sufficient passage for the scower water, if made eighteen feet wide, but may be made as much wider as shall be thought necessary for the convenience of trade.

Now, ■ there will be but about five feet of descent of the surface of the water from the entry of the dock at the river Hull, to its passage out into the Humber opposite Hazel Gate, we look upon it that its velocity through the dock will of itself be too feeble to drive out the silt, it will therefore require to be aided by setting in a large number of men with col-rakes and other instruments to raise the mud and silt, as many tides, once or more in a year, as shall be found sufficient for the purpose of getting rid of the intermediate accumulation; beginning in the middle, and going as near the sides as shall be judged convenient to the security of the walls, for the middle being cleared to a sufficient extent, the grounding of vessels near the sides will continually be pressing down the mud from the sides towards the middle.

It is to be noted, that nothing but the present dock basin will require the aid of men to raise the mud; the external passage from the lock to the river Hull, as also from the proposed sluice at Beverly Gates to the Humber, may be kept clean by scowers from the great basin.

We must conclude with remarking, that, with regard to the keeping the great basin clear of mud, there is doubtless a possibility of doing this by machines worked by men and horses, properly contrived for the purpose; and though doubtless this labour will be very great, and at the same time an almost continual incumbrance to the basin, yet as on the other hand the charge will be very great for the additional works above proposed, it might be wished to bring the matter to a computation; but as it would take up a considerable length of time to enter into a detail of this business, which would be necessary for the purpose of an estimate, we must beg leave to postpone the consideration of this matter to some future opportunity; and indeed till the trial that we have already mentioned to be made of the dock shall shew for a certainty what works it will be most needful for the company to take in hand.

Hull,
17th August 1778.

J. SMEATON.
JOHN WOOLER.

To the Honourable the Commissioners of the Customs, and the Chairman of the Dock Company of Kingston-upon-Hull for the time being.

Hull, 24th November 1779.

WE, the underwritten persons being severally appointed by the Honourable Commissioners of His Majesty's Customs, and the Chairman of the Dock Company of Kingston-upon-Hull, in pursuance and by virtue of an Act of Parliament made in the 14th year of the reign of his present Majesty George the Third, chap. 56, for making and establishing public quays and wharfs at Kingston-upon-Hull, having carefully surveyed and examined the sundry works executed by the said company in pursuance of the above mentioned Act, humbly beg leave to report as follows:

1st. That in conformity to the clause, page 9 of the printed Act, directing the works to be done, the said Company have made the bason or dock with a large sea lock, or double sluice thereupon, for the commodious passage of vessels, in the whole extending from the river Hull to within twenty yards of the road, formerly passing through Beverly Gate, being as near to the ancient site thereof as in our opinion it conveniently could be.

2dly. They have dug, and made the same in all necessary parts within fifteen inches of the depth of the bed of the river, as we found it at, and near to the entry into the bason from the said river, and that it now continues of the same depth except in some places near the entrance of the sluice and bason, where the mud has gathered, but which can be cleansed away whenever the same shall become a real inconvenience or impediment, and which as we apprehend comes under the clause for cleansing, page 13 of the said Act to be quoted by and by.

3dly. That the same is capable of admitting loaded ships of great burthens, as it will receive upwards of twenty feet depth of water in spring tides, and as it stands at present, will retain by means of the lock or sluice eighteen feet or thereabouts.

4thly. And that the width or breadth of the bason or dock (exclusive of the sluice and entry which are of necessity contracted) is of a medium of above sixty feet greater than it could have been if the Company had not purchased ground beyond the limits which the ground granted by this Act from his Majesty would have admitted.

5thly. That

5thly. That the said Company have built a commodious quay or wharf, ranging along the side of the said bason or dock next the town, which as it appears to us is of a sufficient and convenient length for the trade and business of the said town and port, and which we can the more readily judge so to be, because it is not only of the full length required by the said Act, but of a greater length by above thirty feet than it could have been made had not the Company purchased the additional ground afore said on the opposite side, being now of the width or breadth of seventy feet.

6thly. That respecting the construction of such "reservoirs, sluices, bridges, roads, and works, requisite matters and things as they (the said Company) shall from time to time judge necessary for the more convenient use of the said bason and dock," as directed in the 9th page of the said Act, it appears to us that the Company have done such of the above articles as are at present necessary for establishing the trade and commerce intended by the said Act, upon the said bason or dock, and the said quay or wharf adjoining, and that the said trade now is, and has been for some months past, carried on with convenience.

7thly. With respect to such of the above discretionary articles, as further time and experience shall suggest to the said Company to be necessary, for cleansing or repairs of the said bason, quay and works, as it is directed by an express clause, page 13 of the said Act, as follows: "That the said Company shall from time to time and at all times hereafter well and sufficiently repair, maintain, support and cleanse the bason or dock, and the quay or wharf, and all other the works, matters, and things by them to be made, built, and provided by virtue of this Act;" it seems to us that the manner of performing the same is left to the discretion of the said Company, whenever it may become necessary.

Lastly. That the public being now in possession of the object required by the act to be done, and within the limited space of seven years,—we do therefore report and adjudge that the works of the said bason and dock, and quay or wharf, are completed according to the intent and meaning of the said Act.

JOHN WOOLER.
J. SMEATON.

WORKINGTON HARBOUR.

The REPORT of JOHN SMEATON, Engineer, upon the Improvement of the Harbour of Workington in the County of Cumberland.

IN consequence of a view and necessary admissions taken of the harbour of Workington upon the 25th and 26th days of November 1776, at the instance of Sir James Lowther Bart. I have considered the same, together with the six first articles of a paper delivered by the gentlemen of Workington, to the following Purport, viz.

The gentlemen of Workington having taken their harbour into consideration, think that it ought to be enlarged as well as repaired, and for that purpose wish to have an Act of Parliament.

What they chiefly want, is,

1. To extend the frame work down the north side of the river Derwent.
2. To repair, join, and preserve the quays on the same side of the river, and to give powers to fix posts for mooring vessels, &c.
3. To secure the river Derwent in its present course so far as may concern the harbour.
4. To repair and extend the middle or merchants quay, and fix posts thereon for mooring vessels, &c.
5. To cut open, widen, and cleanse the south gutt, or mill race, as far up as to a point twenty yards northwards from the north corner of John Smith's house at the low end of the town; and between the said gutt and a breast-work or quay, which is intended to be made between the east end of the present south quay and the said house; and to take off the marsh twenty yards broad along the breast-work or quay already made and to be made between the said house and the low gutter, for ways, moorings, lading and unlading ships, &c.

6. To

6. To make a mole on the south side of the river, to break the force of the sea, and to extend the quay down the Rectory ground to the said mole.

Having therefore considered how far Sir James Lowther's interest and property may be affected by the above proposition, as well as what may be proper to be done for the good of the whole, I am of opinion as follows:

1st. To the first proposition there appears this objection; that by extending the frame work down the north side of the River Derwent, being nearly in a direction N. W. by the compass, and the great Seas that affect this harbour the most being those from N. W. to S. W. all those seas will be caught by the said extended frame work, and will range along-side the north quay in a more violent manner than hitherto they have done, there being no beach on that side for them to break and spend themselves upon, so that the births of the ships lying to load coals, &c. at the north quay and hurries thereupon, will be rendered more unquiet than at present, and which are now the most uneasy situations of any part of the harbour; and not only this, but at the same time Sir James Lowther will be precluded from making a very capital improvement, by an additional harbour on the north side.

2d. To the second proposition I must observe, that this being the property of Sir James Lowther, it is his business to execute: nor can I apprehend that Sir James can reasonably object to such posts being fixed upon the quays on the north side of the river, as may be proper and necessary for occasionally hauling ships in and out of the harbour; and from the quays on the south side, provided the places of those posts be previously ascertained, and limited in such manner as not to interfere with such improvements as Sir James Lowther may think proper to make upon the said north quays and his property there.

3d. To the third I do not see any reasonable objection, provided it be done so as not to interrupt the free course of the river Derwent.

4th. To the fourth the same observations occur as to the second.

5th. To the fifth I do not see that Sir James Lowther can have any reasonable objection, except any should arise from matters of property that do not pertain to considerations of engineering.

Z 2

6th. I also

6th. I also see no objection on the part of Sir James Lowther to the works proposed in this article, provided the head of the said mole be terminated at the place marked out in the plan for the termination of the said mole or pier on the south side, which place is nearly the same as where a heap of stones were placed, which were shewn to me as put there by the direction of the gentlemen of Workington for marking the place of the head or termination of the said intended mole; and provided nothing be contained in the act to prohibit Sir James Lowther from building a mole on the north side, whose head or termination shall be respecting that on the south side, the same as is shewn in the plan, that is, in a direction nearly N. E. and S. W. from each other by the compass, and at a distance not exceeding 200 feet.

I come now to describe the improvements that I should propose to be made by Sir James Lowther on the north side; and look upon it that the space proposed to be inclosed by the new projected pier on the north side will be the most proper; and which appears to me by far the most improvable and eligible situation; for, from the soundings taken, there will be here nearly three feet more water than can be easily obtained in any situation further up the river, which is indeed a very material consideration, because at common spring tide there may be made here by deepening the ground as per estimate full sixteen feet water, and as the neaps are said to run about four feet lower than the springs, there will then be full twelve feet water, equal to the draught of the largest vessels that now frequent Workington harbour as I am informed; an advantage either to the movement of the present vessels, or to the reception of larger that I need not insist upon.

As the bringing out a new mole from the land at high water mark will of itself be a work of considerable expense, it seems proper, in order to reap all the advantage that may be from it, to give the area inclosed a competent breadth. The breadth inclosed here is proposed of about 200 yards, which seems sufficient to contain every improvement that can at present or in future be requisite at this place.

This disposition will also be a very considerable improvement to the stillness of the water at the present quays; for instead of the seas after they have entered the outward heads ranging along the face of the north mole, as would be the case if the frame work were continued to the same point; by the space being left open between the proposed north head, and the present termination of the north frame work, the weight of the sea will in part fall in there, and ultimately meeting a sloping beach, will there be broken and spent, instead of being reflected from one object to another, as is in a great measure at present the case.

Furthermore,

Furthermore, the seas after passing this second opening, finding so very considerable a space to be expended in, the vessels arranged alongside the interior face of the pier will lie in a quiet harbour, and in sailing in they will conveniently bring up by coming upon the sloping ground of this new harbour, and this I apprehend is the whole of what may be originally done: But if the space comprehended between an interior wharf wall, and the N. E. side of the pier, be dug out to the greatest depth proposed, and thus separated from the rest of the sloping bay, the seas that will be propagated through this last contracted entry, will be so broken and dispersed, that the vessels will lie comparatively speaking as still as in a pond; while the outer bay or harbour will remain susceptible of any other improvement that may hereafter be suggested; and in the mean-time be a receptacle for smaller vessels occasionally coming in to take refuge.

It is a possible thing, though not certain, that the sands that drive coastways from S. W. to N. E. may in part get between the outward heads, and meeting still water within the opening between the north pier head and the termination of the frame work may subside and lodge there; and being out of the course of the Derwent at low water, cannot be driven out thereby: for remedy whereof, if this should prove to be the case, I would propose to construct an under-ground tunnel of five feet wide, to communicate the head of the interior harbour with the river Derwent above the iron works quay, in which space there being a considerable fall at low water, such sands would be driven out thereby again into the course of the Derwent, which will take them beyond the outmost heads.

J. SMEATON.

Austhorpe,
8th January 1777.

ESTIMATE for building a new North Pier at the Harbour of Workington.

	£	s.	d.
To the building of 50 rods of the pier on the north side, beginning from the pier head, to be of the mean height of 21 feet, 36 feet base, and 30 feet top, with a parapet 6 feet base, and 9 feet high, at the price of £114 per rod	5,700	0	0
To building 38 rods of the pier, to be the same inside as the former, and of conformable dimensions without, with parapet mean height 5 feet by 4 feet thick, at £79 per rod	3,002	0	0
			To

To building 8 Rods of pier conformable at top to the former, and same parapet, at £32 per rod	-	-	-	-	256	0	0
To digging out the harbour so as to form a clear area next the north pier 85 rods in length and 12 rods width, so as to make 16 feet water at common spring tides, besides what will be used and paid for as fillings between the pier walls including foundations, viz. 40 rods, at £6 per rod	-	-	-	-	240	0	0
45 do at £12 do	-	-	-	-	540	0	0
	Neat estimate	-	-	-	£ 9,738	0	0
Add 10 per cent for contingencies	-	-	-	-	974	0	0
Total of the exterior pier and clearance	-	.	-	-	£ 10,712	0	0

Aufhorpe,
8th January 1777.

J. SMEATON.

ESTIMATE of interior Works, viz.

To 65 rods of interior wharf wall 7 feet base and 5 feet top and 20 feet high, to be faced with squared stones, at £41 per rod	-	-	-	-	2665	0	0
To 56 rods of tunnel 5 feet wide, for opening an occasional passage of water from the river Derwent, if found necessary for scouring out the north harbour, at £15 per rod, including extra work about a draw gate for opening or shutting the same at pleasure	-	-	-	-	840	0	0
					£ 3505	0	0
Add 10 per cent for contingencies	-	-	-	-	350	0	0
					£ 3855	0	0

Aufhorpe,
8th January 1777.

J. SMEATON.

Second REPORT of JOHN SMEATON, Engineer, upon the Harbour of Workington.

PURSUANT to the request of Sir James Lowther, Baronet, signified to me the beginning of September last by Martin Dunn, Esquire, I took the opportunity upon the 20th December last to reinspect the harbour of Workington, attended by Mr. James Spedding and Mr. Thompson Ship master of the said place; and the subject of my present view being, as stated to me by Mr. Dunn, to consider by what means the entry into the present harbour might be best facilitated, I accordingly made such observations and enquiries of the gentlemen who attended me, as tended to be clear in this matter; and also took such measures as appeared necessary for the forming an estimate; from all which I am of opinion that if the frame work were extended in such manner as was agreed upon in London, when the clauses relative to the engineering part of the proposed act were settled; and which was particularly described in the beginning of the clause marked D. that this would be the most likely means of facilitating the entry of the harbour; the description whereof in the said clause is as follows: " And whereas it is apprehended it will be useful for the navigation of the said river, that the said frame work of the north side the said river should be extended and carried downwards from the north-west end of the said work, one hundred yards, according to the present direction thereof, the top of which to be not less than one foot higher than the highest spring tide that has been known at Workington. To be filled solid to not higher than within four feet of the height of what is solid in the present frame work; and that the pile work from the said frame work should be extended downwards to where the low perch now stands."

The above extract was the collective sense of the different parties concerned at the time, and which if enacted into a law must have been executed accordingly; but this not having been the case, and being as I now apprehend, called upon to give my opinion what it may be proper for Sir James Lowther of his own free will to execute; I look upon myself at liberty to give my particular opinion, which is, that I do not apprehend it necessary to construct the frame work so high as specified in the above extract, for a very extraordinary tide having happened at Workington in September 1776, that was near upon five feet above the common spring tides; and this frame if to be one foot higher than that must be six feet above the same; it appears to me quite sufficient if the new frame work be raised three feet above ordinary spring tides, which will be so much higher than the top of the upper rail of the present frame work, as this is barely even with the ordinary spring tides;

tides; also the pile work proposed to extend from the termination of the intended extension to the low perch, being designed solely for the keeping the water in its present channel; it appears to me that this work may be deferred till the river has shewn some symptoms of its being likely to change it; for as, according to the accounts set forth in Mr. Jessop's report, it has continued in this channel sixteen years; and the channel itself is now formed in a very compact bed of gravel to a depth from five to six feet below the general surface of the flat gravel beach to the north, with very gradual slopes on the sides, it does not present appear to me very likely to change its course; and unless positively necessary, the pile heads proposed to be driven may occasion damage to ships if they should happen to stick upon them, if they should be driven out of the channel, when otherwise they might not touch, or else stick upon a gravel surface much nearer to a level.

It also appears to me that the proposed extension of the frame work will add to the security of the channel's remaining where it is, without the use of pile work; and that in case the funds will not properly allow the execution of the whole of the proposed one hundred yards at once, that fifty yards may be first done, which will also ascertain the utility that may be expected when the remainder is executed at a future time; for this reason, and as the propriety of the execution of almost every thing depends upon what it will cost, I have very carefully considered the probable expense of extending the frame work per yard running. The top to be three feet higher than the present frame work, and the solid to be four feet lower than the solid of the present frame work, which will obviate the objection to the extension of the frame work (according to its present dimensions) contained in my first report of the 8th January 1777, and supposing the extension to be carried on in a firm and substantial manner, with Riga or Memmel fir balks of twelve inches square for the main timbers firmly bolted together; and the frames at no more than five feet distances middle and middle; this I make to amount to the cost of £13 4s. per yard running, and therefore for 50 yards £660, and for the 100 yards, to £1320.

This work may be done at a less expense if done in a slighter manner, that is, with timbers of less scantlings, the frames at greater distances, and less iron work; but the savings that will thence arise, I cannot recommend.

*Authorpe,
3d March 1778.*

J. SMEATON.

PLYMOUTH YARD.

To the Commissioners and principal Officers of His Majesty's Navy.

The REPORT of JOHN SMEATON, civil Engineer, upon the defective Works in Plymouth Yard.

HONOURABLE SIRS,

CONFORMABLY to the matters suggested in your letter to the Right Honourable the Lords Commissioners of the Admiralty of the 5th April last, a copy of which you were pleased to put into my hands, and agreeably to your request to me for that purpose, I have viewed the defective works in Plymouth Yard, and having been conducted in my view thereof by the officers of the yard, I beg leave to report to your Honors such opinion thereon as by their appearance in their present state, assisted by the said officers and artificers, I am enabled to do; and having viewed the whole range of wharfs and frontage works from Mutton Cove at the south part of the yard to and inclusive of the Graving Place, my observations were as follows:

1st. That the cove, formed at the south part of the yard by a circular pier or wall, is carried up upon a rock foundation to the height of about eight feet with Portland blocks, in front, of a breadth from three feet to three feet six inches in bed; and which being flat jointed and set in terras mortar, appears to stand firm and unmoved. Above the height aforesaid, the external of the wall both inside and out are built with limestone or marble ashlers, of above one foot height of course or thereabouts; and said to be in bed from fourteen to twenty inches, which were also set in terras mortar; but on the outside principally and chiefly, for about four courses above the Portland blocks, the marble ashlers are bulged outwards; and that in so regular a manner as can only be accounted for by some regular cause which has taken place at the same height, and not from accidental violence or derangement: and though this bulging is most conspicuous in the circular part of the wall above mentioned, yet the same kind of appearance extends in a greater or less degree from the circular pier above mentioned, through the whole range of wall that fences in the ponds before the mast houses; and as the greater length of this range is built upon rock and the other upon a timber foundation; and as that on the timber is in general as free from the derangement of bulging as that built upon rock, I must conclude that the bulging

ing of the wall throughout this district has not been occasioned by any failure in the foundations.

2dly. On this head I am informed, that the backing, or what may more properly be called the fitting of the wall betwixt the two outsides, (both of which were squared stones set in terras,) was wholly done with rubble masonry, built with common mortar. Now it appears to me from the whole course of my experience, that no composition of mortar made with lime burnt from Plymouth marble with common sand will ever concrete into a hard stony substance if constantly under water, or subject to be frequently wetted by the return of the tides; or even remain hard after getting some degree of induration in first setting, unless it had the opportunity of becoming dry, which never can happen to works thus exposed to the frequent influx of the tides. The consequence that naturally follows, is, that the weights that are upon the interior parts of works resting upon matter that is soft and yielding, its endeavour is to burst the external coat; the Portland blocks being large, well squared, and weighty, have been able to resist the action of the semi fluid contents; but the marble ashler being lighter and less in size, with a greater number of joints (and which in the usual way of working, are less close behind than before) though they have proved firm enough to prevent the joints from being actually opened; have not been sufficient to prevent that kind of swelling which constitutes the bulging of the walls now to be seen. Had the backing of these walls been performed with the same kind of rubble stone that was really used, laid in a mortar that would grow hard under water, then those derangements could not have happened from the causes above-mentioned. If also the walls had been backed with brick and common mortar, as the joints would have been comparatively small, and all the matter reduced to horizontal bearings, the action of that infinite system of wedges, composed by rubble, and laying in every direction, and aided by common mortar, as in its original state like grease, to make them slide, would have been avoided, as well as the lateral tendency to spread thence arising.

I took notice of one place in the wall before the mast pond, where the marble ashler had not only bulged, but the joints had opened on the backside next the pond, where it was tolerably fair without, which was generally the case; but this was accounted for by a heavy Dutch vessel driving against it. On this occasion I must observe, that those walls, having no support by a weight or backing of earth lying against them (which together with land ties, &c. receive the greatest part of the shock) appear to me too slight in point of thickness (being only about six feet at the top) to sustain the shocks of vessels in hard weather; if they had been built for vessels to lie against them. This observation will appear confirmed by this remark, that the wharfing fronting the slips, which are filled up with

with earth solid behind the walls, are in better condition than those behind the mast pond which stand single; though those walls, like a part of those against the mast pond, have been built on timber, the front of which has been destroyed by the worms.

3dly. Respecting the article of the destruction of the foundation timbers by the worm, I must remark, that the proper and effectual remedy has already been taken by the officers and artificers of the yard, viz. That of laying a footing of rubble before them, so as to engage the mud, warp, and fullage to cover them, for being so covered, all experience shews that the worm cannot subsist to hurt them.

4thly. No part of the works appears to have suffered so much derangement as the south pier leading into the south channel, though this has been built with Portland blocks from the bottom to the top, it does not want for backing of earth, is of a circular figure, and the Portland blocks have not only like the rest been walled with terras mortar, but a certain portion of thickness of the rubble on the backside of the wall has been walled in terras also. This part is built upon plank and pile, which in like manner as the other has been destroyed by the worm, and which in like manner as the other has been underpinned and footed with rubble, so that in that respect it may be said to be secured. The middle part however of the backing of this pier, was like the rest done with rubble work in common mortar, and which probably aided in a degree by some kind of settlement from the softness of the foundation, as well as from the destruction of the timber foundation by the worms, has had so great an effect by endeavouring to burst the outward case, which though of Portland blocks it has by spreading opened the upright joints in several places to the extent of two inches, though from the largeness of the beds of Portland, it does not appear to have bulged in any considerable degree. This work having been underpinned and footed as already mentioned, and many of the joints filled up with thin stones in terras mortar by the artificers of the yard, it would appear from these joints not opening afresh, that the work is now come to such a settlement and bearing, that being made good as it now stands, it may be likely to prove lasting.

6thly. The north pier of the south channel, together with both the entering heads of the graving place, have been all built in a similar manner to that of the south pier of the south channel; they are underpinned and footed with rubble on account of the same effects of the worm, and have shewn themselves subject to the same kind of deficiencies, though not in an equal degree; and which have been also in part repaired. There is however one open upright joint in the west face of the south head of the graving place that remains open nearly upon three inches; and one of the terminating stones of the south altar of the graving place

ing of the wall throughout this district has not been occasioned by any failure in the foundations.

2dly. On this head I am informed, that the backing, or what may more properly be called the fitting of the wall betwixt the two outsides, (both of which were squared stones set in terras,) was wholly done with rubble masonry, built with common mortar. Now it appears to me from the whole course of my experience, that no composition of mortar made with lime burnt from Plymouth marble with common sand will ever concrete into a hard stony substance if constantly under water, or subject to be frequently wetted by the return of the tides; or even remain hard after getting some degree of induration in first setting, unless it had the opportunity of becoming dry, which never can happen to works thus exposed to the frequent influx of the tides. The consequence that naturally follows, is, that the weights that are upon the interior parts of the works resting upon matter that is soft and yielding, its endeavour is to burst the external coat; the Portland blocks being large, well squared, and weighty, have been able to resist the action of the semi fluid contents; but the marble ashler being lighter and less in size, with a greater number of joints (and which in the usual way of working, are less close behind than before) though they have proved firm enough to prevent the joints from being actually opened; have not been sufficient to prevent that kind of swelling which constitutes the bulging of the walls now to be seen. Had the backing of these walls been performed with the same kind of rubble stone that was really used, laid in a mortar that would grow hard under water, then those derangements could not have happened from the causes above-mentioned. If also the walls had been backed with brick and common mortar, as the joints would have been comparatively small, and all the matter reduced to horizontal bearings, the action of that infinite system of wedges, composed by rubble, and laying in every direction, and aided by common mortar, as in its original state like grease, to make them slide, would have been avoided, as well as the lateral tendency to spread thence arising.

I took notice of one place in the wall before the mast pond, where the marble ashler had not only bulged, but the joints had opened on the backside next the pond, where it was tolerably fair without, which was generally the case; but this was accounted for by a heavy Dutch vessel driving against it. On this occasion I must observe, that those walls, having no support by a weight or backing of earth lying against them (which together with land ties, &c. receive the greatest part of the shock) appear to me too slight in point of thickness (being only about six feet at the top) to sustain the shocks of vessels in hard weather; if they had been built for vessels to lie against them. This observation will appear confirmed by this remark, that the wharfing fronting the slips, which are filled up

with

with earth solid behind the walls, are in better condition than those behind the mast pond which stand single; though those walls, like a part of those against the mast pond, have been built on timber, the front of which has been destroyed by the worms.

3dly. Respecting the article of the destruction of the foundation timbers by the worm, I must remark, that the proper and effectual remedy has already been taken by the officers and artificers of the yard, viz. That of laying a footing of rubble before them, so as to engage the mud, warp, and fullage to cover them, for being so covered, all experience shews that the worm cannot subsist to hurt them.

4thly. No part of the works appears to have suffered so much derangement as the south pier leading into the south channel, though this has been built with Portland blocks from the bottom to the top, it does not want for backing of earth, is of a circular figure, and the Portland blocks have not only like the rest been walled with terras mortar, but a certain portion of thickness of the rubble on the backside of the wall has been walled in terras also. This part is built upon plank and pile, which in like manner as the other has been destroyed by the worm, and which in like manner as the other has been underpinned and footed with rubble, so that in that respect it may be said to be secured. The middle part however of the backing of this pier, was like the rest done with rubble work in common mortar, and which probably aided in a degree by some kind of settlement from the softness of the foundation, as well as from the destruction of the timber foundation by the worms, has had so great an effect by endeavouring to burst the outward case, which though of Portland blocks it has by spreading opened the upright joints in several places to the extent of two inches, though from the largeness of the beds of Portland, it does not appear to have bulged in any considerable degree. This work having been underpinned and footed as already mentioned, and many of the joints filled up with thin stones in terras mortar by the artificers of the yard, it would appear from these joints not opening afresh, that the work is now come to such a settlement and bearing, that being made good as it now stands, it may be likely to prove lasting.

6thly. The north pier of the south channel, together with both the entering heads of the graving place, have been all built in a similar manner to that of the south pier of the south channel; they are underpinned and footed with rubble on account of the same effects of the worm, and have shewn themselves subject to the same kind of deficiencies, though not in an equal degree; and which have been also in part repaired. There is however one open upright joint in the west face of the south head of the graving place that remains open nearly upon three inches; and one of the terminating stones of the south altar of the graving place

place has its joint open to the same extent, but this has been apparently deranged by external violence.

7thly. The steps in the south channel are greatly deranged below the high water mark, (though very entire above it) notwithstanding they have been twice repaired by the artificers of the yard; which shews that as the steps at the head of the graving place have been very effectually repaired by the said artificers, there is something wrong in the original design thereof; and this appears to me to have been a want of solidity of thickness in the frontage wall, against which the steps have abutted; and a want of cramping the steps to the said frontage wall; besides all which, the interior part of the solid or backing work upon which they subsist having been built with rubble in common mortar (except that part behind each step that supports the tread of the step ne above is set with brick in terras mortar) and there being in this place an outburst of salt water from the main wall, this washes out and paps the common mortar, so that the least degree of frost will rend a work of this kind, however well it might be done with the materials under the circumstances mentioned.

8thly. The last thing viewed was the clerk of the rope yard's office, which as I am informed was built about eighteen years ago. A settlement has taken place in the whole except at the north end; which had it settled also, the whole front would have stood fair. The north end it seems was built upon a wall of a reservoir which is upon a rock; the rest is supposed to have been built upon planking, which having decayed about eight years ago, the above settlement took place, amounting to about two inches and a half perpendicular; and as this subsidence is nearly regular, it is most naturally accounted for as above. On this head I must observe, that it is generally accounted the most difficult of all foundations, that of being partially upon a rock, and partly upon a softer matter, because here being a manifest inequality, it is one of the most difficult problems in architecture, to form a judgment of what may be sufficient as an artificial strengthening, to make it equal with that of a rock which can suffer no compressure. Planking is the common expedient, and where it lies under water and so buried in the ground as not to be subject to drying, it appears from the works of former ages to be sufficiently durable; but where laid in loose or made ground, so as to get a partial dryness as may be presumed in the present situation) it appears subject to the rot in a moderate course of years, and therefore to compressure. A much better expedient in such a case is to pave the foundation and build upon the pavement (laying a course of flat stones upon it) rather than upon planking. The whole is only a small building; and it is said not to have settled further of late years, the rebuilding of the whole front is no great matter, but it appears to me that the taking it down to the chamber and raising that floor may be sufficient, or even drawing and rectifying the facings, putting on the additional height under the roof may answer the end.

9thly. Having

9th. Having said as much upon this last subject as seems necessary, and as it is a matter of a very different kind from all the rest, I shall now lay it out of the account, and proceed to further observations upon the rest. It appears to me that the general causes of all the failures in the works before specified, have been a want of perfection in the art of making mortar, and a knowledge of the proper materials from whence it is best to compound it, for works that are either constantly under water, or in such a situation where they never can become *dry*; nor can this be properly ascribed as a fault to any one, as the first investigation of this business was brought forth by necessity thirty years ago, in the building of the Edystone lighthouse, and though the same compositions and methods have been applied and improved in my subsequent works ever since, and consequently known not only to the respective artificers employed, but always freely communicated by me to all such as desired the knowledge thereof, yet not having been published, I find even at this day they are very far from being generally known.

10thly. As I have already intimated, I lay it down as a fundamental position, that no composition can be made with lime burnt from Plymouth marble, nor any limestone of the nature thereof, or of common white chalk mixed with sand, which composes the common mortar, that will ever acquire a stony hardness under water, or where it can be perpetually supplied with moisture from the daily flow of the tides. But lime from the same kind of stone or chalk when reduced to a dry powder (as usual by quenching) and mixed with half its quantity (by measure) of Dutch terras; and well beaten together for many days successively, without sand, will acquire a stony hardness under water, after it is first set in building, which it generally speedily does. This composition, commonly called terras mortar, has been in use time immemorial, and if well performed and diligently applied, very sound and good work has been performed therewith, but even this mortar will never acquire the hardness of good Portland stone, which I have by trials and experiments been able to attain: but though this lime used for terras mortar is generally of the cheapest kind, yet the terras is so dear a material, having been for many years from three to four shillings per bushel in the light dry powder, and the quantity of mortar made therefrom is so small, and that with so great an expense in the labour of beating it (in general nearly half the value of the material) that it has in general been very sparingly used: in terras brick-work, one brick in breadth on the outside is generally deemed sufficient, very rarely more than a brick length; and in ailer work, sometimes four inches and a half of the joint within the face, sometimes nine inches, and at most as in the works of his Majesty's dock yards, the whole ailer or Portland blocks are set in terras mortar.

11thly. This

11thly. This dearth of the material, and conceiving the above as sufficient to defend the inside works from the immediate action of the water, has induced the backing as it has been called, to be generally performed with common mortar: but brick has for this purpose been generally preferred to rubble or rough stone, because the thickness of the mortar joints will be less, and the surfaces lying level one upon another, they support one another like pillars, with very little tendency to spread; and this kind of work when built within dams, which often for months together give time to the mortar to acquire a degree of hardness and consistency, as is the case in building the King's docks; I say this kind of work seldom shews any deficiency. But in the wharf walls which are generally done by tide work, where the water flows over the whole every tide, the common mortar work never acquires any competent hardness, but when covered up by the heaping on of fresh materials of the same kind, though thereby defended from the immediate action of the water, it has never in any length of time where I have had the opportunity of seeing old works taken to pieces, acquired more than the consistence of compressed *curd*, which with fresh beating will become mortar again fit for the trowel. This kind of work therefore (tides work) coming to the most severe trial of any, we must not wonder, if while it is taking time for compression, it shews symptoms of internal weakness: the want of certainty therefore of answering its end, with credit to the artist and artificer, has led me further to study how to get a composition of mortar for such kind of works, that will internally as well as externally acquire the hardness of stone, and that without greatly exceeding the price of masonry in common mortar.

12thly. The investigation of a composition for the Edystone has in its issue led me to this point. To recount the steps taken, would be tedious as well as not to my present purpose; suffice it to say, that as all the work there was close jointed, the *expense* of terras mortar was no object; but the length of time it required to beat it to the best consistence, was likely to prove a very material impediment. This induced me to make trial of lime burnt from every species of lime stone I could then hear of or procure, and I found that as much depended upon the quality of the stone from whence the lime was burnt, as upon the indurating ingredient; and that the desired effect was produced by the use of a lime from *Aberthaw* in Glamorganshire; but the lime actually used, was of exactly the same nature, and came from Watchett in Somersetshire, on the opposite side of the British Channel, where the same stratum runs, and is in both places called *Blue Lias*.

13thly. In these original experiments, I had the satisfaction to find not only that terras mortar made up with this kind of lime, in lieu of the common sort, greatly exceeded

exceeded in hardness common terras mortar, but needed no more beating than common mortar *ought* to have; and also, that this kind of lime beaten up with common sand, (*without terras*) was almost as strong as the common terras mortar could be rendered by any degree of beating, and superior to it, if the latter was but indifferently beaten; and that salt water to this kind of lime for under water work, was as good, if not better than fresh, which was a circumstance very material to my views at that time.

14thly. It was not till some time after this building was erected, that I found this species of lime stone was not confined to the neighbourhood of the two places mentioned, but it was a fresh discovery of the most agreeable kind to find it in several and very distant parts of this kingdom. This put it in my power to try further experiments, and to use it in works where a much greater degree of economy was required, than in the mortar of the Edystone, and from various trials I found that two measures of this kind of lime to one of terras, or Pozzolana from Italy, beaten up with three measures of sand, coarse and fine mixed, made a composition of equal goodness with that of the Edystone mortar, but doubled the quantity, or that could be made with the same quantity of terras, in the common mixture; and that eight measures of this lime to one of terras or (Pozzolana) and sixteen measures of sand (fine and coarse) made a mortar for backing very nearly equal to the common terras mortar; and as the greatest part of the bulk of this composition is common sand, its price per load in most situations will not much exceed one-fourth of that of common terras, nor much more than double the price of common mortar. In many places where stone naturally rises in flat beds, as the blue lias itself does (and is used for building-stone in the countries where it is found) as also the Purbeck ailer, &c. and the ell and edge stone, brought as flat paving from Yorkshire, all of which being used as backing, where from situation it can be procured at a moderate price, this greatly lessening the quantity and vacuity of joints even compared with grey stock brick work, and thereby lessening the quantity of mortar in a rod of work, thereby reduces the expense of mortar to be no greater than that of the common sort, and at the same time making a stronger bond throughout, produces firmer masonry; but in all cases as the bond made in converting the *whole* into one *mass of stone*, takes away the necessity of using such massive stones for the front (which is generally the most costly part of the work) it follows, that in all cases of water buildings, by the use of proper water lime, instead of the common sort, they may be done at an equal, and in many cases at a less expense, as well as a much greater degree of solidity and certainty, than by the common constructions, with the common materials.

15thly. I call

15thly. I call the lime for these purposes by the general name of *water lime*; for after I found its properties not confined to the blue lyas stone, but even residing in a certain species of chalk which is to be met with near Petersfield in Hampshire, as pointed out in the said Committee of engineers' report, and which at Portsmouth is commonly known by the name of grey lime; but I had also found it near Lewes in Sussex, and there called clunch lime, as also at Guildford and Dorking in Surrey; but what is of most consequence to the present business, as I am informed by scientific friends whom I can depend upon, that the true blue lyas is in quantity at Lyme in Dorsetshire, and I have myself observed it not very far from thence at Axminster in this county.

16thly. I am sensible I might have spared myself the greatest part of this disquisition, but as I humbly conceive it may tend to lead your Honours into the true nature of this business, it will in effect tend to shorten what I should otherwise have to observe upon particulars; to return therefore to my immediate subject.

17thly. As from information I do not find that the defective works (the stairs excepted) have lately given way, I would suppose they have settled till the parts are come into contact; and therefore may probably remain so for many years, before they need rebuilding, as before noticed; and as the effect of the worm has been remedied in the most judicious way of which, as far as I know, the subject is capable; I do not see that any thing can be done more effectual, than carefully to point and make good the joints wherever they are found defective, with the best composition above mentioned, and when the upright joints will admit thereof, to cut Purbeck flat paving stones, a very small matter wedgewise; and drive them in with a soft wooden maul, and before closure with the last pierce, to cram in as much mortar as possible, of the same kind mixed with pebbles, where the joints will take them, with the end of a board or battan; the mortar being rendered a little more fluid, by a small addition of water. This will not indeed take away the *appearance* of the bulging courses, but for this I see no remedy but to take down the walls to the top of the Portland blocks, and then if the rubble contents in common mortar are taken out, and the whole built in with the different kind of mortar specified (though of the same stones) I shall not be apprehensive of any further bulging or settlement, except it should arise from the foundation; and of that where there is nothing but soft matter, into which the piles can be driven, I do not look upon in the nature of the thing there can be any absolute certainty.

18thly. Respecting the steps in the south channel, I would advise their being taken down till there appears something solid to build upon, and to wall the inside core or backing with

with the composition given, called Portsmouth terras, made with the water lime from the lyas stratum at *Lyme*: to build the front wall with a string course of at least eighteen inches thick, cutting the outward stones into steps out of the solid; and cramping every other step to the front wall, which would be still more satisfactory if these front stones of the string course were formed from blocks of moor stones cut into three or four steps each: the steps themselves to be carefully bedded in the best composition, and carefully pointed, so as entirely to exclude the water; and proper conduits to be carried through the work, to take off the outbursts of salt water from the main wall: the work will become still more solid, if there be no occasion to continue the steps so low, as suggested by the officers.

19thly. It now only remains that I advert to the question contained in your letter of the 5th April, before referred to:—that is, “whether rough masonry at the back of the aisslers would not (on account of the irregular figure of the latter on the outside) if carefully performed, answer as well as brick, which being of a regular form cannot be so well worked into the back of the aisslers, nor bonded with the rough masonry in the interior parts of the work, in which case the whole would not be so well connected together?”

From what I have already said, your Honours will perceive, that the resolution of the question depends upon that of another; with what sort of cement is the work to be performed? If it is to be with the best composition of water lime, as I have mentioned, it will together constitute one solid stone, and then it will be of little consequence what may be the relative figure of the parts: and that this will be the case in a certain degree, if done with well-beaten terras mortar, your own observations have proved; for on examination of the back side of walls so built (being those on the south side of the graving place, and at the north side of the south channel) though you found them “not done with square masonry as the contract directed,” yet the rubble masonry in terras wherewith they were done “appeared *very sound and firm*.”

20thly. The rough masonry in terras has been reported by the master bricklayer to be more expensive to the contractor, than if done with square masonry in terras, and this is confirmed by my own calculation, and will readily appear to your Honours when it is adverted to, that in rubble masonry there is at an average nearly double the quantity of vacuity that there is in square masonry, even if but rudely squared, and which must be filled with the most costly of all building materials, videlicet, terras mortar. Yet I cannot agree with the master bricklayer in supposing it *better*, because as the getting

of mortar of any kind perfectly well beaten, may be esteemed the most difficult part of the whole; I should always prefer that construction which at the same expense had the most stone in it, and the least quantity of vacuity to be filled with mortar of any kind.

21st. If the question regarded dry work, as common mortar of common lime and sand will, if well beaten and proportioned, come by length of time to the hardness of stone, then I should judge the rubble work so performed to be equal to brick; because it would then be in the same predicament as water work performed with proper water cement. But if the work is supposed to be under water, as the common mortar as already observed will never come to a stony hardness, I judge that kind of rubble work to be greatly inferior to brick for backing, as pressure will make it tend to spread, which it has been observed from their figure is not equally the case with brick. Besides, as brick is a more dry and absorbent body than marble and most kind of stones, it drinks up the moisture, and causes the mortar to set more speedily, and by that means often gives a greater opportunity of its acquiring some degree of firmness before the water comes upon it, which in this case is a considerable advantage. I therefore cannot recommend rubble backing in works under water, where better materials can be had, and more especially in tide works, where there is the least opportunity of the mortar's setting by the drying quality of the air.

J. SMEATON.

BRIDLINGTON PIERS.

The REPORT of JOHN SMEATON, Engineer, upon the state of the Bridlington Piers, with the most probable means of preserving the same from the destruction of the worm.

THIS Harbour for shipping, formed artificially by the piers at Bridlington quay, being at the bottom of the great bay constituted by the great projecting point of Flamborough Head, with the coast tending from thence southerly, is not only situated commodiously for the reception of the coasting traders, when they cannot make the Humber to the south, or Whitby on the north, but the piers are so disposed as to afford all possible shelter for vessels within them. A harbour therefore so situated, and so constructed, being found to be of great utility, its piers have been erected and upheld at a great expense, but they have at first been built with timber probably with a view to the saving in the charge that would have accrued by constructing them with stone, it has unfortunately happened, not only that these piers are subject to the gradual decay that necessarily must attend all works of wood, when exposed to the action of the sea, but also to a particular kind of decay arising from the continual eating of a certain species of worm, that infects the timber work of this harbour, greatly differing from the common worm whereby ships are destroyed, and which is said to have been originally brought from the West Indies.

The object of my view of these piers made at the desire of the Commissioners for the preservation thereof, the 29th, 30th, and 31st of December last, was not with any intent of improvement of the disposition of the piers and works, but altogether to consider and give my opinion upon the best method to be taken in future repairs, and for the preservation of what is now standing.

I have now very seriously considered these propositions, and however difficult it might at first seem, I now hope to be able to lay down a very practicable method whereby a great deal of expense arising from the decay of the worm may be avoided; but that what I have to offer may be clearly understood, I beg leave to state what was pointed out to me by the pier master, and which appeared to me upon inspection to be the case respecting the nature of this worm, and its operation.

This worm appears as a small white soft substance, much like a small maggot, so small as not to be seen distinctly without a magnifying glass, and even then a distinction of parts is not easily made out; it does not attempt to make its way through the wood longitudinally, or along with the grain, as is the case with the common ships' worm, but directly, or rather a little obliquely inward; the holes made by each worm are small proportioned to the size of the worm, but as they are so many in number as to be but barely clear of each other, as they do not appear to make their way by means of any hard tools or instruments, but rather by some species of a dissolvent liquor, furnished by the juices of the animal itself; it follows that as the animals which overspread the whole surface of the timber exposed to their action, proceed progressively forwards into the body of the wood, the outward crust becomes macerated and rotten, and gradually washes away by the beating of the sea, so that in fact the timbers, planks, &c. gradually waste in size and thickness, till at last becoming so weak to support the strain upon them, they are obliged to be replaced and new done many years sooner than would happen by the natural decay of timber in such circumstances, if unaffected by the worm.

The worm is found lodged in a crust of wood, generally from a quarter to half an inch deep, that part of the wood under this crust remaining perfectly sound. The rate of progression, as I am told, is, that a three inch oak plank will be destroyed in eight years by action from the outside only.

It is furthermore observed, that those animals do not live except where they have the action of the water almost every tide, for they are not found in the timbers above the level of common neap tides, high water, or indeed scarcely so high; so that it is to be inferred, that if any happen to fix so high as the common neap tide mark, if a few low tides fall out together with still water, as frequently happens in summer, the worm thus unwashed dies, and a stop is put to its further progress higher.

Again, it is very obvious that so high up as the piles and work are covered with sand, or as soil lies against it, the wood is perfectly free from the worm, so that the parts affected are what are also exposed to the air, that is from the surface of the ground or sand to high water neap tides. Whether a deprivation of the action of the sea water, accompanied by a continual change every tide, or a deprivation of the benefit of the free circulating air each tide, occasions the loss of what is necessary to their subsistence, may be a question, but which indeed it does not seem necessary now to resolve; this however is the fact; for on the inside of the planking against which the ballast, sand, or gravelly matter which is heaped by way of filling and giving solidity to the piers' base, and which in general is filled above the high water neap tides, is also found to be a preservation to the

inside

inside of the planking, though from the outside only they will waste, as has been said, three inches in eight years.

The rebuilding those piers with stone would doubtless be an absolute cure of the evil complained of; and if they had fortunately been done so at the first it would have been well: but as it appears to me that it would be impracticable now to construct those piers of stone, without a much larger fund than there is any likelihood of being raised for the purpose, it remains only to make the best of them as they now stand; I say impracticable without a much larger fund, because if attempted to be proceeded with gradually with stone upon the present funds, the progress would be so slow, that a great part of the present piers would be down, and the harbour open, before it would come in turn to replace them with stone, so that the repairs of the timber work must still go on, and if it exhausts the present funds to keep the present works in repair, a double outlay would in consequence be incurred to which the present funds would be inadequate; and though the timber repairs would gradually lessen as the stone advanced; yet it would be several years before the outlay on the current repairs of the timber piers would become a very material and sensible easement; for these reasons, despairing of seeing any thing very extensive done here with stone, I have very seriously applied my mind to the propositions laid before me, which in substance are, however, to make the best of what now is.

It will also be necessary, for the clear apprehension of what I have to deliver, that it be understood how the outside of the timber work of the piers, that is, what is subject to the worm, is formed. It is observable that the outside of the piers is formed by a strong row of squared piles of oak, in general about a foot square, and near the pier heads the spaces between them not much more than the breadth of the piles. Inside of those they are planked with three-inch plank, in the general old ship plank, but of late years there being a scarcity of this, fir plank has been in some places tried, which is found still more subject to the worm than oak; this planking is to keep in the ballast, wherewith, as already mentioned, the piers are filled; and which preserves the inside of the plank from the worms, while the outside being exposed to the free action of the sea, is subject to their incroachments in the manner that has been mentioned, and not only the spaces between the piles, but also behind them; because as there is seldom a water-tight joint between the plank and the back side of the piles, the sea drives in, and nourishes the worms; as also in the joints between plank and plank, and thereby widens them, so as in time to let the sand and small parts of the ballast wash out through them, which on this account needs replenishing from time to time: it is also obvious that the piles themselves will be exposed to the worm on all sides, for by the same rule that the worm gets into the plank behind them, they will affect the back side of the piles, the other three sides being open to them.

It

It is doubtless on account of the speedy decay and consequent weakening of the piles, in the very part of them where the main strain lies, that it becomes necessary to plant the piles so near together, and hereby a much greater expense is incurred than would be necessary if they were subject to no other decay than what length of time would produce, that is in case there were no such worm, or what would amount to the same thing, in case the worm could be effectually shut out.

This latter, viz. the shutting out the worm, appears to me very practicable, the method whereof for new outside work I will now describe. Suppose the piles driven and lined with planking in the usual way, only a little more pains taken than heretofore in squaring the sides of the piles that look one towards another; when the work therefore is completed, I would begin by amending the squaring the sides of the piles, so as to reduce them to straight-sided figures; then I would adapt chocks of fir to these spaces between pile and pile to be driven lengthways, and which being separately fitted and driven in may be very nearly adapted to the place that each is to occupy; and between every layer there is to be a bed of tar and oakum, or tar and hair, which is to be crammed into every little vacancy that appears after the driving in of each chock, and so to go on stratum super stratum between every vacancy between pile and pile, till you come just above the height where by experience you find the worm to cease; in short you may then consider all the spaces between pile and pile completely walled up with short blocks of fir, bedded in tar and oakum, and all the vacuities completely filled with the same substance. This done, the chocks being left a little swelling before the face of the piles, the whole is to be dubbed off with an adze to one general surface, upon which a sheathing is to be put on in the manner of the sheathing of ships, the whole surface of which to be filled with sheathing nails, which, affected by the salt water, will throw a coat of iron rust over the whole surface, and preserve the work from the worm, in the same manner as in the sheathing of ships. It is not improbable that this crust of iron may be wholly impervious to the worm for many years; but suppose that in the compass of ten or twelve years it should be found that the worm had got through the sheathing, new sheathing may then be put on at a very light expense, and the work guarded for as many years more, and so on as long as the main timbers will last from the absolute decay of time.

In the execution of this method I would observe, that I would begin the lowest tier, layer, or stratum of chocks, as low as I could well get for water, or as low as there is any probability of the sand or soil being taken away, and continue them up to where the worm ceases, and thereby putting in kant pieces, the sheathing will be reconciled with the back planking, and so continue from thence to the top of the pier.

Again,

Again, I have mentioned that the sides of the piles ought for the sake of the more regular fitting in the chocks to be a little better squared than common, yet I do not mean by this that the timber ought to be wasted or weakened by being hewn dye square; it is sufficient to bring the prominent places to a square, leaving the wainy parts to be brought nearer by being notched in with a chissel after the main work is fixed ready for the chocks; for as I suppose every chock particularly adapted, it is no matter that they should be all exactly of a length, or their ends be a perfect square; and I would also further remark, that if the chocks are made out of stuff about six inches square, so as to take two breadths in the thickness of the piles, they may be both made much more readily, and more completely fitted than if attempted to be put in from whole balks. I would also add, that in case in time the soil should happen to wash below the ground tier of chocks, so as to leave the under work exposed to the worm. In such an accident it will be better to drive a row of ground piles about six feet from the pier, and fill the intermediate space with chalk stones, &c. so as to retain soil against the chock work, than attempt to put in chocks under the former, to which in such circumstance it may be difficult to make a good joint.

This kind of work will doubtless require a little care and attention, but will be subject to no real difficulty or hazard, nor be attended with any considerable expense; and indeed were this expenditure altogether additional, the quantum would be no ways proportionable to the duration it will communicate to the work; for if it be considered how much solidity this method will give and the whole being preserved of its original strength, there will be no need of allowance for wasting on account of the worm, so that it will rather appear in the light of a saving; for I am fully of opinion that if the piles are put at two feet spaces, where they are now put at one, or at three feet spaces where they are now put at two, they will in reality be in proportion more strong and valid than at present; and that the saving of so much prime and valuable oak timber will nearly pay all the other expenses.

I come now to lay down what is to be performed to preserve the work already done, and not as yet so far decayed as to require new; and I suppose the sides of the piles not having been driven with any view to this kind of treatment, will be found to be irregular and require too much cutting to bring them to plain surfaces every where, but in many places this may be done, and indeed every where a chock may be fixed in front by going in bevil, and fixing by a couple of spikes; by this means at least the front may be made good; and as the decay of the outface of the planking may be attended with such irregularities as cannot be fitted with chocks, I would recommend these spaces between the front chocks and back planks to be made up course by course with brick and terras mortar, which will grow hard in the water, and enable the whole of these irregular cavities to be filled completely full of matter, so that the worm will be thereby as effectually killed, and a fresh

a fresh growth prevented as in the new work. The faces of these chocks being then neatly dubbed off along with the faces of the piles, and a sheathing put on as before directed, I have not the least doubt but that such parts of the work as, though considerably decayed, still remains strong enough to resist the violence of the sea, will be preserved for a considerable term of years, that otherwise would be in a few years in a state of ruin.

Besides the above described works that compose the outside of the body of the piers, there are, at certain intervals, still larger detached piles driven as fender piles, which are equally eaten away by the worms as the others; to those I would only advise that their whole surface on every side be driven or filled with sheathing nails from a little below ground to neap tide mark as before recommended.

As it appeared to me the whole of the north pier head lies dry to the ground at spring tides in moderate weather, but if it should happen that any part cannot be easily come at to fix the low tier of chocks within the ground, I would begin by laying a tier of the large block stones close against the foot of the piles, and in some degree adapted thereto, kanting off the outward angle, and fixing each stone by two strong dogs or iron cramps one near each end of the block, the dogs to be firmly fixed at one end to the piles or timber works, and the other leaded into the upper surface of the stone, then ramming full every cavity between the blocks and the timber work with bricks and terras mortar, the chocks may be founded on this, a little below the upper surface of the stone blocks.

A further requisition from me, was, in what manner the block stones already provided may be most effectually applied?

As I have already shewn how the worm may be prevented, and even stopped where it has already entered, without much use from stone work, it will follow that much the greater quantity, said in the whole to amount to 750 tons, will remain on hand.

I observe that the cliffs to the eastward of the north pier are greatly wasted by the continual beating of the sea, and in a way of wasting still more; so that in process of time, it may be justly apprehended, that unless something be done to controul it, the sea will make its way into the harbour; and indeed had it not been for a great number of the block stones that have been promiscuously tumbled down into the external angle, between the north end of the north pier and the main land, that has prevented its direct progress that way, it is not unlikely but that this would have already happened, a circumstance that would be fatal to the harbour, as the case would be very different here from what it is from the want of junction from the west end of the south pier with the main land, as the sea only comes through the beach by recoil, after having in a great measure spent its fury upon the beach; whereas here, it would come in by the most direct passage into the very place where the principal ships lie.

It

It appears therefore to me that those stones being already upon the place, cannot be better disposed of than by securing this neck of land, in lieu of using a quantity of timber work in this place also, that otherwise might be necessary. The most easy and simple way of constructing such a bulwark, and what seems to me best calculated for receiving and diverting the shocks of the sea, is for the face of the bulwark to be disposed in a circular form, and the ground course let down its whole thickness, or thereupon into the solid clay. I do not mean that there should be any work upon the blocks, except what is done to bring them to a steady bearing in place; and except what may be necessary for the stairs in case a stair is thought indispensable, and which I would otherwise advise to be avoided, to shun the making any break into the regular face of the works.

As the surface of the clay bottom appears to be in a state of wear by the action of the sea though seemingly slow, yet it may be expected that in process of time it will so wash away as to expose the matter upon which the ground course is founded to the action of the sea, and therefore it would be the regular course of business to found the ground tier of blocks upon a sheet of plank piling; but if it is considered that this sheet of plank piling is equally liable to be laid bare, and when so, must for the same reason as the piers, be defended by something else; and as it is probable that it will be several years before such defence will become necessary; and when necessary may be defended by letting down another row of blocks at the foot of the former; it seems to me, that the original expense of pile work may for the present be dispensed with; and besides doing the work specified a considerable quantity of the block will still remain, they may not only be applied to the occasional purposes before mentioned, but also in making good the insertion of the bulwark into the main land, as the cliffs gradually wear away.

I do not mean that any mortar or cement should be used in the construction of this bulwark; but to prevent the gravelly matter from washing through the joints of the blocks, I would advise a stratum of heather to be laid upon the chalk stone fittings; and also the joints of the back sides of the blocks to be well crammed up with the same; or in lieu thereof hay may be used for the same purpose.

J. SMEATON.

Aufborpe,
15th May 1778.

SUNDERLAND PIER.

The REPORT of JOHN SMEATON, Engineer, upon Mr. SHOUT's plan for rebuilding and extending the old pier of the Harbour of Sunderland.

HAVING carefully viewed the harbour and piers of Sunderland, and received the information of several eminent masters of ships belonging to that port, having also considered the plan produced to me by Mr. Shout their Engineer for the improvement of the said harbour, I am of opinion, as follows:

1st. That nothing appears to me so likely to improve the depth of water over the bar (which is unanimously represented as the most desirable circumstance wanting towards its improvement) as the prolongation of the old pier to the low water mark at the least; and as the direction of the last stretch of the old pier has been now proved by many years experience to afford a sufficiency of shelter to the shipping from out winds and seas, and also to be in a commodious direction for going in and out; I am of opinion, that what has been shewn by experience to be right, ought not to be essentially altered; that is, that the head of the advanced pier should be in the line of direction as the present pier.

2dly. That as a considerable part of the old pier from the head inward appears shaken, and its foundation sapped, I see no more easy or proper mode of repair, than that of erecting it on a new foundation; and as by doing this, according to the plan exhibited by Mr. Shout, a projecting part of the pier will be taken off, that now appears to disturb the current of the river, and break its force in time of great land floods, which are the principal agents towards scouring the channel and keeping down the bar; the current of the river will thereby have a more direct course to sea; and being preserved in one direction by the pier from spreading, will not only make a deeper channel alongside of the pier, but, acting more directly and immediately upon the bar, deepen the channel over it in like proportion.

3dly. I therefore approve of the plan of Mr. Shout, but look upon it that it will be an improvement to the safety and shelter of vessels within the head, that instead of carrying it out in a direction parallel to the terminating direction of the old pier, gradually to bring the new pier round, so that its terminating head may be in the same individual place as if the old pier were extended to the same point.

4thly. As

4thly. As the new pier is carrying out, the effect of it will be seen, and the degree to which it ought to be extended more certainly judged of; but I am of opinion it cannot be too far extended, even beyond the bar, if circumstances of time and expense will admit.

5thly. I apprehend it will be proper to begin the extension of the pier from somewhere near upon abreast of the present old pier head, and to carry it on to some length, suppose about two years work, before any of the old pier is removed; then to work backward removing the old pier, as the new one advances towards the point of junction, by which means the shelter to the harbour will be preserved.

6thly. As I am of opinion, that as the extension is carried on, the north sand will follow it nearly at the same distance as at present, whereon the seas in like manner breaking and spending themselves, will keep the harbour in the same degree of quietude, with the advantages mentioned of a deeper channel over the bar.

Gatehead,
16th January 1780.

J. SMEATON.

N. B. The old pier ■ it is removed must be as entirely eradicated as possible, that nothing of wood or stones may be left to prevent the land floods from deepening the channel in the ground upon which the old pier now stands.

TINMOUTH HARBOUR.

REPORT on Tinmouth Harbour's Mouth.

June 21st, 1769.

HAVING this day viewed the harbour of Tinmouth, and particularly that part of the entry thereof lying between the Low Lights and the Black Middens, I am of opinion, that it will be a great addition to the security of vessels entering and going out of the said harbour, if the stones that are scattered upon the north shore, between the Muscle Scalp and the Low Lights, were removed. These stones in some places extend themselves into the channel, so that ships that happen by accident to take the ground, often receive damage that would be prevented by their removal, and also by affording a greater width and capacity, would greatly add to the conveniency of vessels working to windward either into or out of the harbour.

The rocks called the Prior Stones, I am of opinion for the same reason should be removed and made level, together with such others as obstruct the channel as far as they can be got at.

The stones that lie near the Black Middens may be stowed away in the hollows of the ledge of rocks, so as to strengthen and increase the utility thereof as a break-water, and which if carefully deposited in the method of a pile of cannon shot, I am of opinion will lie where they shall be placed. Those at a greater distance may be laid in the same method on a ridge extending over the highest part of the ground between the Black Middens and the shore, which will also add to the break-water, and in some measure prevent the current from dividing near high water into two channels; and as to those stones that lie up nearer the Muscle Scalp, they may be deposited under the high cliffs, and will tend to the defence and security thereof.

Those stones may be removed in different ways, each of which according to circumstances may have its advantages; and indeed I would advise them all to be tried, from whence it may be with certainty determined, which is executable at the least charge.

1st. The smaller kind of stones may be moved by hand-barrows.

2dly. The larger kind may be split with gunpowder and mauls, and then removed by hand-barrows.

3dly. They

3dly. They may in some places both large and small be removed by Carts.

4thly. They may be removed by lighters laid on shore, and loaded at low water, and removed on tide of flood.

5thly. They may be drawn over the rough ground by windlasses and tackles, to be moved from place to place, as need shall require.

The stones may be laid hold of by eye-bolts, fixed in holes bored by a jumper, or they may be harnessed with chains.

I would advise that the workmen at times employ themselves upon those stones that lie lowest and nearest the channel, and the flow of the tides obliges them to retreat, to work upon those that lie higher.

I observe that a great many stones to be removed are very good lime stones, which, if broken up, I apprehend many would be glad to remove for the sake of the lime.

J. SMEATON.

P. S. In coming down by way of South Shields, I observed a place called the Mill Dam, which, if the trade requires it, may be very properly converted into a wet dock, that would hold a great number of ships.

SCARBROUGH PIER.

To the Commissioners of Scarborough Pier.

GENTLEMEN,

I WAS duly favoured with your order of the 15th of May last, from the hands of Mr. M'George, referring to a case to be stated by Mr. Gilbert, for my opinion thereon, and also respecting the carrying on the works of the pier in future, which case was also inclosed, describing the method by which the works were proposed to be carried on. All which having carefully considered, and having referred to my former plans and estimates, I find, that in the course of twenty-five years, there have been executed from my designs and directions upon principles similar to the mode of operation described in the case inclosed piers for the following harbours, videlicet,

Aberdeen, Aymouth, Portpatrick, in Scotland; and St. Ives in Cornwall:

all of which have answered and given entire satisfaction. The outside stones of any of the above were not above three tons weight, nor were they backed with any thing but promiscuous fittings, from a ton to about a cube foot in a stone; the general weight of the fitting stones were about half a ton in a piece. It is however to be observed, that the whole were quarry stones, rough and angular, and not rounded by the action of the sea. We used no gravel for wrecking the work, but in what was above low water, the interstices were filled by hand, after set with small sharp rubble stones of the same kind; and it is to be further noted, that the outside blocks, after being roughly squared, were not laid upon their beds, but set with their angles upwards, so that every stone was jambed between two, set in a similar manner below. I am therefore of opinion that the method proposed will be sufficient to resist the violence of the sea, when got up to its full height, and covered with an entire platform of large blocks upon the top.

In regard to the economy that may attend this mode of operation, I must observe, that in all the piers above mentioned the whole or by far the greatest part of all the stones employed were not found by the sea shore, but by necessity brought from quarries by land carriage, so that the expense upon the whole was not less than four shillings per ton; and would have been far greater, had nothing but large blocks been employed. It may therefore in some situations be better economy to make use of the stones that are there,

there, if large, though rounding, and to fill all solid, than either to break them to render them angular, or fetch this kind of stones from quarries within land. It seems therefore probable that something may be done by way of easing the expense, and increasing the expedition; but the proper mode of operation depending altogether upon local circumstances, I am unable to form my opinion fully thereon without a view of the premises.

I am with great respect,

Gentlemen,

Your most obedient humble servant,

J. SMEATON.

Ausborne,
9th August 1781.

ESTIMATE for improving and enlarging the Harbour of Scarborough, in the County of York.

	£	s.	d.
To extending the present pier 150 feet, containing 115 ton per foot running, at 6s. per ton	5,175	0	0
To building a new inner pier, containing 320 feet in length, and 31 ton per foot running, 6s.	2,976	0	0
To making a wharfing to confine the sands, extending 1,300 feet, at £2. per foot running	2,600	0	0
To clearing the present area of sand, so as to make 11 feet water at a spring tide by the side of the wharf, containing 31,300 yards, at 6d. per yard	783	0	0
To making a groyne or jetty near the space, extending 900 feet, for preventing the sands from circulating into the harbour	900	0	0
To making a basin 100 feet square, and laying pipes for keeping the sand from lying before the wharf	1,000	0	0
To erecting 5 new dolphins, and other posts for mooring vessels; and other contingencies	500	0	0
To contingencies upon the whole	2,000	0	0
	£15,934	0	0

SHIELDS DOCK.

ESTIMATE for lengthening the Dock at North Shields, so as to make it in the whole 237 Feet Length between the heel of the present Gates and the crown of the Arch at the upper end of the Dock; and also for the erection of a pair of interior Gates, as per Design of John Smeaton.

To digging out the upper stratum supposed pan rubbish to the mean of 9 feet deep, the ground being opened 63 feet wide at top, and to be 60 feet wide at bottom of said depth, will contain	cube yards	2133			
The lower stratum supposed a clayey sand		2248			
Total excavation digging 6d. loading at 3d.	4379 at 9d.		164	4	3
Drainage of the water, suppose 4 men employed at a time, that is 8 men for 24 hours, and this continued for three months or 90 days at 18d. per man per day			54	0	0
To leave for laying the stuff			25	0	0
Clearing the foundations			£ 243	4	3

CARPENTRY IN THE FLOOR.

To 1 pile per yard running under the string piece in the front of the wall, being 9 inches diameter, and 9 feet long, of beach, elm, alder, or fir timber, will be in number					81
To 2 piles under the middle of each beam or groundfell, which, if at 3 feet distance, will be					70
To piles, timber, making and driving			151 at 10s.	75	10 0
To 35 beams or groundfells at 3 feet distances middle and middle, 33 feet long 12 x 12 containing	cube feet	1155			
To 242 running of string piece 12 x 6		121			
To timber and workmanship		1276 at 1s 9d.			111 13 0
To 2 piling machines at £3 each					6 0 0
To trenails of 18 inches long for the string pieces 81 at					
To do 24 groundfells, 70 at					
To 3332 feet superficial of 3 inch fir plank for the floors, timber and workmanship at 6d. per foot					83 6 0
To caulking ditto at per foot superficial					
To 13 cwt. of spikes at 36s.					23 8 0
Carpentry in the foundations, exclusive of trenails and caulking					£ 299 17 0

To ramming in between the walls fells, with a mixture of clean London ballast and quick lime, containing 83 cube yards, at 1s.			4	3	0
To flushing the same with a layer of pozzelana mortar, to lay the planks upon, containing 259 square yards, at 7d.				7	11 1
To filling in the foundations				£ 11	14 1

MASONRY.

To ailer in the side walls, which at the mean thickness of 2½ feet, will contain 12,352 cube feet, which winning, leading, and hewing, at 7½d. per foot			386	0	0
To pozzelana mortar for setting the same ¾ per foot, including extra labour				38	12 0
N. B. 14 tons of pozzelana mortar will be wanted at £2 2s. per ton.					
To rubble stone for backing 1148 yards of 2 feet thick, which will take 1435 fadders of stone, which winning at 3d. leading at 1s. is 15d. per fodder				89	13 9
Mortar for do.					
To 162 fadders of lime at 6s.			48	12	0
To do. of pan rubbish sifted, at 10d.				6	15 0
To 100 tons of sand at 6d.				2	10 0
To setting 12,352 cube feet of ailer, at 1d.					57 17 0
To building 1148 cube yards of rubble, at 1s.					51 9 4
					57 8 0
Masonry in the whole					£ 681 0 1

This comes to 7s. 5d. per the reduced yard upon the whole solid, the mason said it would be done for 4s.

To moating the same with clay, containing at one foot thick, 4838 cube feet at 2d. including the filling in and making good the earth behind the walls				40	6 4
--	--	--	--	----	-----

CARPENTRY IN ERECTING THE GATES.

The Threshold and Barrier at the Gate Heels.

To 185 cube feet of oak and elm timber, timber and workmanship at 3s. 6d. per cube foot measured neat in place				32	7 6
To fir timber, 133 cube feet, measured neat in place, at 2s.					13 6 0
Threshold and barriers				£ 45	13 6

THE GATES.

	£	s.	d.
To oak for the two heel posts, and clapping posts, 78 feet, at 4s. timber and workman- manship included, neat measured in place	15	12	0
To 52 oak keys for the gate bars at 1s.	2	12	0
To 504 cube feet of fir timber, in the gate ribs, timber, workmanship, and measured neat in place at 2s. 6d.	63	0	0
To caulking			
Carpentry in the gates	81	4	0

IRON WORK, &c.

In fixing the thresholds and barriers.

In jagged bolts and anchor at 4d. per lb. 3 cwt. 2 qrs.	6	10	8
In screwed bolts and straps for fixing the main posts, &c. at 5d. 3 cwt. 1 qr.	7	11	8
To spikes for putting on the ribbands and planking, per cwt. 1 cwt. 2 qrs.	2	14	0
Fixing the dormant part	16	16	4

IN THE GATES.

cwt. qr.

To 20 pair of T and L's, weight	7	3	0
To 2 long screwed bolts	2	2	0
10 1 0 at 4½d per lb.	21	10	6
To 2 hoops for the top of clapping posts 1. ½ at 4d.	0	14	0
	22	4	6

Hinges for the Gates, &c.

cwt. qrs.

The pair of upper hinges	2	1	
The 2 heel hinges	1	3	
4 cwt. at 4½	8	8	0
To 2 cast iron beds for holding the gudgeon and forming the heel circle, 5 cwt. 1 qr. at 18s. per cwt.	4	14	6
To 2 copper plates, each 1f. 6i. long, 1 foot broad, and about ¼ inch thick 22lb. at 16d.	1	9	4
Work for the gates to turn	14	11	10

ACCOUNT received from Mr. Walton, after making the Estimate, of the following Articles, not charged for want of knowing the customary price, viz.

81 trenails, 18 inches long, including labor, at 1½d.	0	8	5½
70 do. 24 inches long, including labour, at 2d.	0	11	8
Caulking the floor of the dock, 3332 feet, including oakum, pitch, and labour at 2d.	27	15	4
Do. the dock gates, 576 feet, including do. at 2d.	4	16	0

ABSTRACT

ABSTRACT of the preceding ESTIMATE.

Digging, drainage, and clearing the foundations	243	4	3
Carpentry in the foundation, exclusive of trenails and caulking	299	17	0
To filling in the foundation	11	14	1
The foundation	554	15	4
Masonry in the walls	681	0	1
To moating with clay, and filling in behind the walls	40	6	4
	721	6	5
Total expense of lengthening the dock	1276	1	9

ERECTING THE GATES.

	£	s.	d.
Carpentry in the thresholds and barriers	45	13	6
Do. in the gates	81	4	0
	126	17	6
Iron work in the threshold and barriers	16	16	4
Do. in the gates	22	4	6
Hinges and work for the gates to turn upon	14	11	10
	53	12	8
Erecting the gates	180	10	2
Net estimate	1456	11	11
Allow for contingent articles not included in the foregoing estimate, at the rate of 5 per cent	72	16	7
	1529	8	6

Aufhorpe,
26th May 1775.

J. SMEATON.

TREWARDRETH HARBOUR.

The REPORT of JOHN SMEATON, Civil Engineer, upon the Question of a Harbour in the Bay of Trewardreth, Cornwall, exhibited by Brooke Watson, Esq.

THE design for a bason and an entering vestibule before me for Trewardreth Bay, appears to me sufficiently well imagined as to its shape and position, respecting the points of the compass and the adjacent coast; but the entering vestibule, which I apprehend is principally intended to shelter the gates, whereby the water of the bason is to be held up to its destined height, appears to me by far too small to produce that effect. In this area I have drawn a circle of 100 feet, that is of 33 yards diameter; and the whole area will scarcely amount to a quarter of an acre. It does not signify what, or how great the area of the bason may be within the gates; because this will have no influence on the quieting the outward port or vestibule; and therefore, suppose a sea runs in with a strong wind at S. E. (I mean right into the opening), and is therein reflected from the different piers and walls, it will manifestly tend to the destruction of the gates; as from the measures they must necessarily be placed so near these walls, and receive their strokes in one direction or another, so very frequently, that I do not apprehend any timber work upon that scale will be found stout enough to endure the shocks for a length of time.

If the necessary occasions for the size of ships were less in proportion, as it might be more useful to lay out a less capital upon a project of this kind, then, as the entry of a port might be made less in width, in the same proportion as the ships themselves were less, it might perhaps be brought about, that a small harbour could be rendered as quiet as a large one; but since the necessary occasion for width in the entry of the port, is not smaller in proportion as the area of the harbour is smaller, but to the width of the largest ship intended to enter it, then a very small port may have an occasion for as wide an entry as a large one; and consequently the quietude of the shipping lying therein, will be less (perhaps in a greater proportion) than the increase of width, to that of its area.

I do not know that it has yet ever been ascertained, what is the greatest width to be admitted to the entry of a port, in proportion to the number of acres it contains; or what amounts

amounts to nearly the same thing, what will be the proportion between the width of the mouth of the port and the mean diameter thereof. In the present case the width of the entry is thirty feet, that of the area of the vestibule about 100; that is a little more than one to three; certain it is that I do not recollect ever to have seen the area of a port so confined, where it has been enclosed with a wall; and where a large pair of gates are to be protected, I should imagine the internal space should be far greater. I should think a mean diameter of 300 or rather 400 feet quite little enough, or the vestibule still preserving the width of thirty or at most thirty-five feet to the mouth; and even this mouth will be quite little enough to admit a vessel of twenty-seven or twenty-eight feet to enter with tolerable facility.

It being supposed that the figure of the outward harbour or vestibule is near upon right, its dimensions may be increased in any proportion; and if there were a want of space, a part of the proposed area of the bason may be taken into the vestibule: True; but here will be a great addition to the walling in proportion to the area of the bason, and capacity for the entertainment of ships.

I think it my duty to suggest, that every part of the works exposed to the sea in the bottom of this bay, ought to be done in the most substantial manner, otherwise failures may be expected; and how far the occasions of trade in this place will render it a profitable undertaking, to encounter the necessary expenses should be well considered before the execution is resolved on.

It is generally allowed that Milford Haven is one of the most complete natural harbours in this kingdom; but let it be reduced by a suitable scale to two or three acres of area, and the width of its mouth reduced from three or four miles, to thirty or forty yards; it will then become a much more unsuitable design for a harbour than this under consideration.

J. SMEATON.

Grays Inn,
18th January 1792.

(See Plate 9.)

The REPORT of JOHN SMEATON, Civil Engineer, upon the Harbours
of St. Helliers and St. Aubin.

HONOURABLE SIRS,

HAVING at the request of the honourable the Governor, made a voyage to Jersey upon the subjects above specified; and having personally resided in that Island from the 5th to the 13th of June last, both inclusive; and having during that time diligently observed and considered whatever appeared material, in consequence of the matters given me in charge by the honourable Committee above mentioned, I beg leave to report as follows: stating first, the principal matters respecting the harbour of St. Helliers.

That with respect to the harbour of St. Helliers, the matters of complaint stated were, want of capacity for holding vessels; and want of quietude when lying therein.

The pier of St. Heliers appears to be of the construction that may be properly denominated a screen ; being a work of that kind, where, in the first formation, the greatest degree of shelter may be procured at the least expense ; it has therefore the advantage of doing, in its origin, the greatest quantity of work for the least money ; and were this form attended with no disadvantages, this would in all cases be the most proper way of proceeding. But as this kind of pier naturally turns its back towards the sea, and its mouth towards the land, upon the supposition of a sloping shore as commonly happens ; if an extension of the pier is wanted for an enlargement of the harbour, it naturally brings the entrance into shallower water ; whereas, when piers are extended from the shore towards the sea, a further extension of these piers naturally gains deeper water.

The pier of St. Heliers having been fixed and supported at a considerable expense, in proportion to the funds of the island, it would be useless to consider how it ought to have been



been planned, were every thing at this day in a state of nature. The proposition is to make the best use of it, as it now stands; and considering it as a part of a whole, to procure at the least expense, more room and better shelter.

Had it not been for the shoaling of the water at the entry, the first thing that would naturally strike, would be to extend the present pier further to the north, and to meet it with a catchpier from the north-east corner of the new quay. This contracting the great width that the mouth bears to the capacity of the harbour, would at once render it more ample and more quiet, and would be the most easily done, as the materials for both piers could be carried progressively from the pier, but in the opinion of the pilots, as well as the committee and gentlemen consulted upon the spot, the shoaling of the water is an invincible objection; in which opinion on full consideration I find reason to concur.

Of the number of plans exhibited to me, that had been the fruits of the study of different gentlemen of the island, the idea most generally adopted was, to begin a pier, detached from the present, at some point betwixt the present pier head and the new quay, leaving about 120 feet or upwards of opening betwixt the present and new pier head; then carrying it on in a straight direction, somewhat near parallel to the face of the new quay, to leave a space between the new pier and the new quay for vessels to lie; and by extending it northward in the same direction towards the town, as the funds for carrying it on admit, to give it every suitable enlargement that the occasions of trade may now or in future require.

This idea in its general outlines and purpose seemed to me well adapted to the occasions of the Committee, but yet was likely to be subject to one capital inconvenience. I was told that when the wind was at N. W. which point being clear of Elizabeth Castle and rocks, the fetch of the sea, then lying open from the whole extent of St. Aubin's Bay, in blowing weather, causes the vessels to ride unquiet in St. Helliers harbour. Now any pier carried on in any direction parallel to the face of the new quay, or trending more westward, will have a great effect to bring the waves that will necessarily range along the face of it with such a wind, directly into the mouth of the harbour; and if to avoid this, it has a bearing given it more eastward, will confine the additional room proposed to be made in the harbour between the new quay and the town, so near the shore, that the depth of water as well as room therein will be too much curtailed. A further objection is, that when vessels are coming for the harbour before the wind, through their proper channel, or opening through the rocks, which as I understand lies at W. S. W. from the pier head; or coming with any scant wind, from that point to the S. E., after turning

ing the head to go into the harbour, they will have the wind in their teeth; and as they may not always be able to shoot into the harbour, there will not be sufficient room to *bring up* before the harbour's mouth, without being in the way of those that may follow them under the same circumstances. It appears to me therefore that every inconvenience may be avoided, and the desired end attained, by forming the pier with a curve towards the head, according to the plan I have now the honour to lay before you; and conformable to the idea of which I left you a sketch on leaving Jersey, and which being verbally explained to the Committee, seemed to give general satisfaction.

According to this disposition, the north-western seas will meet the curve of the pier towards the head, in such an angle, that they will be turned from the harbour's mouth (as will appear by considering the position of the north-west line A. B. fig. 1.), and not be turned into it, as would be the result, if the pier were to be continued in the straight line, or any one parallel to it, and which in this case would leave too great a width of mouth for a harbour of this size. But this affords ample space to come-to, in the lee of the harbour's mouth, and afterwards warp in at leisure. It will also afford a superior advantage in getting out with north-westerly winds, by getting under sail from the present pier head.

This, according to my judgment, will be the way to make the best of St. Helliers harbour, and furnish the desiderata at the shortest expense. Yet it must be adverted to, that no small harbour can be made a very quiet harbour; for the magnitude of the waves are supposed the same to all, and the necessary width of the mouth for a ship to enter the same; seas then that in a degree will inevitably wrap round the heads, will affect a smaller harbour more than a large one, though of similar constructions; for the effect of the waves in disturbing a harbour is greater, in proportion as the lineal width of the mouth is to the whole area of the harbour. In this respect the harbour of St. Helliers is, and always must be, defective. Another circumstance tends much to render a harbour unquiet, and that is, when they are bounded with walls. The waves of the sea follow the laws of the pendulum, which when once set a vibrating would never cease, if not stopped by friction and the resistance of the air. The same would happen to the libration of the water if there were nothing to stop it; for meeting with walls and objects comparatively smooth, the waves are not destroyed, but reflected into another direction; and from that into another, till they are gradually destroyed by friction. The speediest way by which waves are destroyed (that is by friction) is by forming a surf, and breaking upon a sloping beach, sand, or rocks; in which also the harbour of St. Helliers is defective; there being no part of its circumference, where the seas have an opportunity of breaking and spending themselves,

themselves, the bottom of the harbour excepted, which is a part of the natural shore, extending on the S. E. side about thirty fathom, betwixt the old and new quays; and which, if opportunity should occur, it would be well to extend. The new quay, which, as I was informed, is principally a cover to rocks, though it seems to afford great utility in other respects, yet by preventing the seas from breaking upon them, will naturally have the effect of rendering the harbour more unquiet; but which, when the new pier is built, will become extensively useful, especially when the cross wall is formed to the northward, and the north side of the new quay is wharfed up:

EXPLANATORY OBSERVATIONS ON THE DESIGN.

THE catch pier as it is here shewn extends 520 feet: but I expect that it will have a considerable effect in quieting the harbour, by the time it is carried out abreast of the north corner of the new quay, that is, from and including the head, to the length of 250 or 260 feet. This will eventually make more room in the present harbour, that is, the vessels can lie closer by being more quiet; and will also actually increase the room by the space betwixt the face of the new quay and the new pier; for then I expect two tier of vessels may be laid before the face of the new quay, and be screened, not only from the N. W. but all other winds.

When the catch pier is carried out to the length as shewn in the plan, the cross wall built, and the area inclosed freed from the encroaching rocks, then the additional room will be fully double of what can now be occupied. It is true, and I apprehend must remain a truth, that the sands, this way, lie higher than in the present harbour; but the interior harbour being considered as a place of deposition, the very great spring tides that reign here, (which rose above low water mark, the spring tides when I was there, no less than forty feet, though that was a time of the year when the tides in general run short), will enable large vessels to get into it, and out, for more than a week together during the time of spring tides; and though the neap tides here in general run shorter than any place I have before had an opportunity of noticing, in proportion to the spring tides, being, as I am informed, in general but from nine to ten feet, yet this being constantly the case with large vessels in tide harbours, can be no objection here.

Here being no back-water, and the interior harbour a place of great quietude, the sands may be expected to gather; but to prevent this as much as possible, I would recommend an expedient, that I observe has been judiciously and successfully practised; and that is, the making low arches or gully-holes underneath and through the body of the

the pier; one of which passes through the same about 200 feet from the pier head. It is about six feet wide and four feet high, so that a person cannot walk under it upright. This aperture has the effect of preventing the sand from lying on the inside in quietude; so that keeping it somewhat disturbed, by the agitation of the seas, it is ready to be hauled out on the retreat of the tide: and I have no doubt, but that it has greatly contributed to prevent the sands being lodged in the harbour to a greater height than they are, and their gradual increase; for I observe the ground of the harbour at and near the interior mouth of the gully, at C. is full eighteen inches lower than the ground at D. being the point equally distant from the gully and the pier head. Were this stopped up, I have no doubt but that in a little time the ground there would become higher.

In this view of keeping down the sand, I would recommend gully-holes to be made in the catch pier, at the distance of 120 feet, and disposed as pointed out in the plan at G. G. This will make four gullies in the main body of the pier, and two in the cross wall; but being frequent, I would not advise their being above four feet wide, and three feet and a half high in the crown; and the effect of the first will be so pointed out, before a second is needed to be pitched, that if the dimensions I have assigned, should be too large or too little, the effect will speak for itself, and be remedied in the subsequent*.

With respect to the construction of the pier, I would recommend it to be built with rough granite, in the same manner and style of workmanship as the works of this harbour have already been carried on. I would recommend it to be filled with rough quarry stones to the middle, without any intermixture of gravel or rubbish. The height of the platform at top of the pier I suppose to be the same as the new quay; and as I do not suppose it a place of business, it is very possible it may do without a parapet; but if on raising it to that height, experience shews one to be wanted, it can be added at pleasure. For that reason I have not supposed any stairs, as strong upright ladders bolted to the walls at proper places, will be a sufficient convenience for the purpose. The construction and dimensions of the pier will sufficiently appear by the detached plan and section (fig. 2.); and as there always occurs a difficulty in turning the convex parts of pier heads when composed of rough stones, that is, so to tye in the stones so as not to be fetched out by the surge of the sea; in the plan that I have given of the ground course of the pier head, I have shewn the manner in which I directed the catch pier head of Aberdeen† to be formed, which is also of granite; that is, with anchor stones and dove-tails, somewhat upon the idea of the dove-tail work of Edystone lighthouse.

* It is possible that some of these may be of disservice, while others are of service, in which case the former can easily be walled up.

† The reader may refer to this plan in the third plate, page 49 of this volume.

If it could be afforded, it would be well to form every course in this manner; but I apprehend it may be sufficient to do this at every five feet in height; so that beginning with the first course that rises above the ground, there will be six courses bonded in this way; and which will be completed by sixty anchor, and sixty-six dove-tail stones, and which, if not more easily had elsewhere, will be undoubtedly afforded by the quarries of Montmado. Though in the plan they are somewhat regularly disposed, yet they are no ways required to be of equal sizes; all that is wanted will be, that each stone be adapted to its next neighbour.

A very material article that remains is the expense of the work; but this being entirely local it is not possible for me to give any specific estimate, but what would be likely to do more harm than good, for if the price assigned by me be too large, the workmen would endeavour to take advantage of it; and if too small, they would not be bound by it; and the Committee not so well satisfied in not getting the work done at the rate given out. But it will be very material and useful to know, that in the first 240 feet, or sixty fathom of pier, including the head, and supposing the mean height, including the foundation, to be thirty feet, that this pier will contain 9,500 cube yards of work; and as I estimate it, will take 19,000 tons of rough materials, exclusive of the parapet.

THE HARBOUR OF ST. AUBIN.

RESPECTING this Harbour the following matters having been submitted to me in writing, I cannot acquit myself better than in giving distinct answers thereto. The paper is as follows:

“ Experience having shewn that the new pier of St. Aubin, called the Upper Pier, intended to bring and lay up ships and vessels close to the town, for the convenience of fitting them out, loading and unloading, is from its situation liable to fill, by the great quantity of gravel which the sea washes in from the back of it; and that the depth of water is, from that action of the sea, diminishing more and more; it has therefore been conceived that the building, instead of this, another pier further out to reach from the point of land called the Bulwark, to a rock called Cavard, in the direction of the fort, will answer every purpose of security, convenience, and greater depth of water, and is not so likely to be exposed to fill as the other.

"It has also been found that the want of a proper road for carts to communicate with the aforesaid pier during the hours of high water in spring tides, is a real inconvenience; as in that circumstance, carts cannot have access to the pier, without going round a part of the town, and up and down again a steep road; wherefore it would be desirable, to procure a proper road by taking upon the harbour, such an extent as may not be prejudicial, and obtaining by that means the additional advantage of a quay or wharf, against which boats and other small craft could be brought up at high water, to take in and out things upon occasion.

"But as it is found by observation that men who want professional knowledge and experience, in respect to the effects of buildings for harbours, and to oppose the sea, are subject to be disappointed in the works they project; it is therefore wished Mr. Smeaton would well consider the above stated work, and give his opinion.

"1st. Whether this new projected pier instead of that now subsisting, is the most eligible plan which can be adopted to remedy the inconveniences of the other? And if not, What other expedient he would advise?

"2dly. In case Mr. Smeaton approved the said plan, Whether it is most advisable to commence the work at the extremity towards the sea, and to continue it towards land to a certain degree of forwardness, before the old pier or any part of it be taken down?

"3dly. Whether he would advise the taking upon the harbour, and in what extent, in order to acquire the road and convenience above stated? And whether this work of the road and quay ought or ought not to be begun, before some progress is made in the building of the intended pier?

"N. B. The time the want of this road is felt, is for the space of about two hours in the mornings and evenings of spring tides.

"Mr. Smeaton is also requested to impart such further advice upon the whole as his skill and experience may suggest."

Answer to the 1st.—As I look upon it the reason why the upper pier, as it stands at present, becomes liable to fill with gravel, arises from this circumstance; that the west end of the island of Jersey lying open to the fetch of the great seas propagated from the Atlantic Ocean, there being no land to shelter it in that direction, that is from the W. S. W. to W. N. W. (according to the true meridian), great seas, of course, with all westerly and south westerly winds, will rake the shore from the Corbiere to Noirmont Point; and turning that, south westerly winds will drive forward the gravel brought along with it coastwise, towards the bottom of St. Aubin's Bay; and in its way meets with the upper pier now erected; but this pier not extending far enough from the shore effectually to intersect

intersect and intercept the course of the gravel, thus continually and successively brought, it is driven round the pier head; and there finding an eddy (which will constitute a place of repose on the north side of the pier), will naturally produce the annoyance complained of. Nor does the effort made use of, appear likely to stop the current of the gravel; for the jetee being low, and pointing directly across its course, the gravel was driven over it, and round it, and the jetee itself in a great measure destroyed. Had the materials employed in erecting this jetee, been applied to carry out the pier head in its N. E. direction, this, flanking the current with a considerable obliquity, would have probably had a perceptible good effect, and had the head been lengthened to its full height, to as great a length in addition as that of the jetee, in all probability this would have in a good part relieved the complaint. I say in a good part relieved it, for the upper pier being too much in shallows, to fully answer the purposes of business, I am of opinion that nothing can more effectually tend to relieve the complaint, and answer the purposes intended, than a removal of the pier, and carrying it out in the direction and extent proposed in the plan exhibited to me; which was, to carry it out from the Bulwark rock, in a direction towards the fort; that is, S. 52° 30' E. to the length of 175 yards, or 525 feet; and afterwards in the direction S. 69° E. to the length of 105 feet: in the whole 630 feet.

To the 2d.—I apprehend the place of beginning will depend upon the situation of the principal and weighty materials. If they are to be brought or floated by water to the place, then they can be best deposited at the pier head; and carrying on the work towards the Bulwark rock, to that degree of forwardness that the new pier becomes a shelter, which experience will point out; then the materials of the present pier may be removed, to fill up the gap and join the land. But if the materials are principally to be brought from the land, then the beginning from the Bulwark rock and advancing forward progressively, will be found to be the easiest and cheapest mode of proceeding, as well as the safest from derangements. And thus carrying the work forward till an equal shelter is found to what is afforded by the present pier; then this last may be begun to be removed, in order to carry the other work forward; beginning in taking down with the pier head. I think there is this objection to the beginning at both ends, as then there will be two unfinished terminations, always lying open to the derangements of storms.

To the 3d.—I must observe, that a degree of inconvenience will always be outweighed by a superior utility. In my discourse upon St. Heliers harbour, I have fully pointed out, that where a sloping shore is interrupted by the erection of a wall, as a wall has not that tendency to spend and destroy the waves of the sea that a sloping shore constantly has; wherever walls are erected in the confines of a harbour, it is rendered, in a degree, less quiet

quiet by this means. That there will be a difference is evident and demonstrative; but degrees of quietude not being measurable by a scale, it is not always possible to say what will be the degree of difference. The want of a road to a harbour accessible at all times of tide, is a capital defect; but to the remedy proposed, of taking such a breadth from the harbour as may not be prejudicial, the whole that can be said, is, that the road must be formed and supported by a terminating wall towards the bay, while you are gaining a greater breadth, you are wanting a higher wall; and a higher wall when there is water before it, will more strongly reflect back the waves, instead of destroying them; and those meeting with, and compounding themselves with others, will most undoubtedly render the harbour more unquiet, than if things were, in this respect, to remain as they are. Again, the more useful this wharf wall is made, for laying small boats and craft against it, by a depth of water before it, the more it will tend towards general inquietude; and unless in calm and quiet times, as the face of this wall will lay open to the bay towards the east, I believe those boats will not find it very eligible to lie against it. But yet a road is so great a convenience, that if forty or even fifty feet of frontage be taken from the shore, before the most projecting wharfs (I mean those southwardly towards the pier), as they at present stand; and the wall is carried in a regular curve from thence to join the projection where the road ascends the street; I should apprehend, as this can be wharfed up with a wall of a few feet in height, that its influence at the distance to which the new pier is proposed to be erected, will not be so material as the convenience; but whatever that influence may be at that distance, it certainly will be greater at the distance of the present upper pier, which is much nearer. There possibly might be conveniences and motives in having this road made now, which might make it worth the while to hazard even this difference. But as it does not appear to me, that the want of such a road for two hours a day, for four, or at most five days at each spring tide, can be of great consequence; seeing that at those times, the low water is in the middle of the day, and the interruptions can therefore be only at mornings and evenings, the rest of the day being free of access; and furthermore, that in case of need, the pier is accessible at all times by a road that hitherto has been practicable; all these things considered, I cannot recommend to begin the road and wharf, till some progress is made in the building of the intended pier; or to do any thing that may in its effect be hurtful to the present situation, till a better one is acquired; and the appearance of the benefit, more substantial than the risk.

I am, honourable Sirs,

Your most humble servant,

J. SMEATON.

Gray's Inn, London,
30 Sept. 1788.

QUEENSFERRY SHIPPING PLACES.

The REPORT of JOHN SMEATON, Engineer, upon the Shipping Places at Queensferry, in the Firth of Forth, from a View taken the 15th of August 1772.

IT seems scarcely necessary to say any thing upon the importance of this ferry: it being the shortest and most commodious place of crossing the Firth of Forth, and thereby must recommend itself to the attention of every one who has concern in and wishes well to the kingdom in general; and on occasions is, and may be made more serviceable for the passage of troops, could a bridge be built at this place, though at the expense of £100,000, I apprehend it would become a national object to construct it; but as we cannot hope to see this effected, the next best thing is a commodious ferry; and if it would be worth so large a sum to obtain a bridge, it would surely be worth a considerable sum to obtain the most commodious ferry possible. As matters now stand, there appear to be good vessels well adapted to the purpose in sufficient number, and very able and expert hands to manage them; and even in its present state, from what I have experienced of it myself for years past, I believe it may be said to be one of the most commodious and best attended ferries of the width in Great Britain. The principal defect is in the shipping or landing places of embarking and disembarking passengers, carriages and cattle; what conveniences of this kind there are already are in a great measure furnished by nature, and the disadvantages thereof are such, as where nature requires a little assistance from art.

The principal defects arise from the roughness and awkwardness of some of the present places, for want of proper shelter in particular winds and times of tides, but principally for want of any proper shipping place at all, at or near the low water of a spring tide; by which travellers are often detained when the wind is fair, and afterwards further detained by the winds coming foul.

There are several places of shipping on each side, but most of all upon the south side, and the skippers make use of these as occasion serve; and in fact it is more commodious to have various places on each side than to be confined to one on each side though ever so complete, because from the course of winds and set of tides, they can frequently make their way good between two places without tacking, when they cannot do it between others without great loss of time, and *vice versa* in other sets of winds and tides.

The

The principal shippings on the south side are as follow :

The Binks being the westermost and oldest shipping place ; it fronts the west, and therefore most proper in easterly winds ; it extends to high water.

The Grey Shipping lies near to low water, and is of use only when the water is low.

The Forenefs Shipping fronts east, therefore properest in westerly winds, and serves from somewhat below half flood to high water.

The West Hall fronts east, therefore properest in westerly winds.

The Long Craig fronts west, therefore properest in easterly winds ; this is chiefly used when the tide is low.

The White House fronts and is nearly similar to the former, being further to the east.

North Ferry.

Craig End, the principal shipping place, answers to both east and west.

The West Nefs fronts the west, therefore properest in easterly winds ; is used chiefly when the tide is low.

The Wich or East Nefs fronts the east, and therefore best in westerly winds ; this shipping serves at low water, but is at present very difficult of access.

On communing with the skippers as well as the principal persons at South End and North Ferry, I am of opinion that the shippings which are of the most immediate consequence to improve are the Grey Shipping contiguous to Queensferry harbour and the West Halls on the south side, and the Craig End and the Wich on the north side.

The Grey Shipping seems to have been formerly attempted or made a place, but has been either destroyed by storms or left imperfect ; there is a good mass of stones upon the place, but will need a considerable addition to make it regular and proper ; it will be right to make a face both east and west, and then it will be proper for winds either way, and to build it sloping from low water, to answer such time of tide as the Fore Nefs begins to take place, which serves to high water.

The Fore Nefs shipping wants some repair, and it would seem better if it was made straight and the jetees taken away near the lower end ; but that is not so immediately necessary as the Grey Shipping.

The

The West Halls is chiefly a natural ledge of rocks, standing from low water to high water ; the rocks here want part facing, part building, and part levelling ; the height of this above the sand should not be less than five nor more than six feet.

Some little help is wanted to cut down the face of the long craig from whence it has been begun to low water, in case funds should not hold out after the work at West Hall is done.

The craig end at North Ferry has had the most improvement made thereon of any of the rest, and indeed seems the most important ; but the work wants to be extended to the turn of the point, by which means near two feet addition of water will be gained. This shipping however will not extend to the low water of a spring tide, it is therefore of importance to improve the East Nefs shipping, which has plenty of depth at low water, and is very commodious in westerly winds, and in all other winds that do not overblow. The principal thing wanted here is to smooth down the rough rocks in order to form a road which in its present state seems quite impracticable for carriages and horses ; this may be done by blowing away the irregularities of the rocks, or by bolting down timbers to take the wheels of carriages in the manner of a rail road.

The great irregularity of each of the places that want improvement, makes it not easy to get such measures as would be necessary to form any estimate that can be depended upon without the whole was lined out upon the spot, which would take up much more time than my occasions could possibly allow. But upon a general view of the thing, I am of opinion that if the sum of £500 were raised and distributed amongst the three places mentioned, viz. the Grey Shipping and Forenefs, the West Halls and Long Craig, and the Craig End and East Nefs at North Ferry, the improvements that would be made under prudent management would be such as would be of real use to the public, and demonstrate that such further sum might be necessary to make the whole complete, would merit the aid of those who are enabled to give it.

J. SMEATON.

Edinburgh
26th August 1772.

P. S. The length to be made at the Grey Shipping is 96 yards.
That at the west halls - - - 142 do.
The addition at Craig End, about - 53 do.

And a buoy anchor and chain would be very useful to be laid at a convenient distance off the craig End, to enable the vessels better to haul off and get under way in contrary winds.

J. S.

EDINBURGH BRIDGE.

The REPORT of Messrs. SMEATON, ADAM, and BAXTER, concerning the Bridge of Edinburgh, addressed to the Right Honourable the Lord Provost, Magistrates, and Bridge Committee of Edinburgh.

HAVING been called upon by you to give our opinions concerning the bridge of Edinburgh, in consequence of the unhappy accident that happened thereto upon the third of this present month, we have in consequence each of us minutely examined the state thereof with all the attention we are able, we have also carefully considered every matter of fact that has been laid before us in way of evidence concerning it, and we have fully heard and considered every thing that has been offered and proposed to us by Messrs. Mylnes towards the effectual reparation and restoration thereof; and upon the whole matter we are of opinion as follows:

That not only the particular accident which has been the occasion of this enquiry, but every other matter of a lesser kind of which we have found this structure complaining, has been caused by an overload of earth upon the upper parts thereof, and therefore in general that though the effects of this over pressure has become evident by setts in various parts of the building, yet if the whole be eased of this overload, and properly bonded together, we apprehend that relative to a less weight, the remaining parts of the structure may be rendered firm and secure.

We beg leave to observe by the way, that all heavy buildings are more or less obnoxious to setts, and particularly those where great weights are obliged to rest upon small areas of ground; yet we see buildings stand for ages under those circumstances much more than those cases where they can be relieved of the pressure which has originally occasioned those derangements, and we must further observe that though this bridge were to be taken down and rebuilt with all the skill of Europe, yet it cannot be ensured, but that something of this kind would appear.

We also beg leave to take notice, that the particular accident upon which we have been called, is of a very uncommon nature, viz. the falling in of the three vaults in the south abutment: we can infer in the general that this has been occasioned by an over pressure,

but by what particular circumstance it has happened that the arches of those three vaults have given way in so sudden and so alarming a manner, we cannot at present investigate, but which perhaps will be more fully discovered when the rubbish is removed; this however we infer from it, that as it does not appear to us that the three great arches, with any of their connections northward, have suffered any alteration by the sudden and even momentary destruction of the south abutment, those arches must in consequence be very well poised upon their own legs.

Such being the general causes, and such the general remedies, we come now to the particulars, with the method of reparation pointed out to us by Messrs. Mylnes, with our observations thereupon.

To remove the great overload of earth, Messrs. Mylnes suggest may be effected by shaving off two feet of solid earth from the whole surface of the bridge.

This will certainly have a very good effect in the respect mentioned, and we see no objection to it, save that it will cause the declivity to be in the whole two feet greater; but we apprehend it will still be sufficiently easy; and that it will in some measure obstruct their view sideways, but we may set against this, that the same two feet relative additional height in the parapets, will make a screen to the violence of the wind, which may be expected in some seasons of the year to be too severely felt.

1st. Respecting that part of the north abutment which is filled solid with earth, we observe that the wall on the west side is somewhat rounded, which we imagine has been occasioned by the lateral pressure of the earth within it relative to the great height of the wall, and as this has doubtless happened by laying the earth against it, while the wall was green, it may possibly go no further; but to make it secure, Messrs. Mylnes propose to raise up outside buttresses, as well against the east wall as the west, which we approve.

2d. Respecting the vaults in the north abutment (which are similar to those on the south which fell in, and were the immediate cause of the accident above mentioned) we observe that the outwalls not being bonded in with the arches, are separated therefrom about an inch, at a medium, at the crowns, and the cross walls from which the arches sprung being loaded with a considerable thickness of earth above them, are thereby pressed with a greater weight than the side walls, and have therefore settled, by the difference of from a quarter to half an inch more than the side walls, so as to break the bond between them. These effects are doubtless owing to too great a quantity of earth above these vaults, pressing the walls

walls that support the arches downwards, and the out wall sideways; but as independent of this pressure, we see no reason why the walls should fall, supposing they had originally been built in this manner, Messrs. Mylnes are of opinion it will be proper to lay the greatest part of the space above these vaults hollow by arch work; and also to confine the two side walls together by chain bars from side to side, which we approve; and we beg leave further to offer, that we look upon it, that the best mode of arching in this place, will be simply to raise cross walls upon the former; and upon them to spring new arches over the present, to rise as high as the road will admit.

3d. The small open arch on the north side seems perfectly sound and entire, Messrs. Mylnes therefore think it will be sufficient to lay chain bars from side to side to prevent the lateral pressure of the earth from swaying them downwards, till the whole is hardened and compacted together; now as we understand, there are already relieving arches over that open arch, we also suppose this to be a remedy sufficient, provided the two feet reduction of the height of the road be approved of by the Magistrates, otherwise we think something should be here done by way of avoiding an addition of weight.

4th. The three great arches appear to stand firm upon their legs, as they were built, there are however some splits in particular parts, chiefly in the rubble work of the foundation of the piers, which though proceeding from the unequal bearing that inevitably attends that sort of work, yet would probably not have appeared, had they not been charged with an extraordinary pressure; in order therefore as well to relieve the piers with their foundations as to prevent the lateral pressure of the earth against the spandrill walls from the chance of producing any ill effect, we cannot but recommend any method of arching in the spandrills between the great arches that will effectually save weight in lieu of chain bars across the bridge at these places.

5th. We come now to the small arch on the south side, concerning which the whole of the difficulty lies we understand that previously to the falling of the three vaults contiguous thereto, there was a sett or rend of the abutment wall from the top to the bottom, which extended itself across the small arch as far as the impost of the pier on the north side, which rend not only in the abutment wall but in the arch opened considerably wider than before upon the fall of the contiguous vaults; in this arch the rend divided into two branches, the former almost directly across, and which now affects the piers in a small degree, the new one diagonally towards the north west springer. This original rend we apprehend to be caused simply thus, that the matter of the natural foundation of the abutment wall, being less firm westward than eastward, when the whole became loaded with

the

the superincumbent weight of earth before mentioned, the west side settled, leaving the east side standing firm, and thereby occasioned the rend as first mentioned. The falling of the vaults we look upon as occasioned by some failure of a different kind; though still owing to the general cause of over pressure, it is not therefore to be wondered that this rend before made, should become worse by the great concussion of ground that must have attended the fall of the vaults, with all the matter above them. In this state of things, Messrs. Mylnes are of opinion, that it is absolutely unsafe to take down this small arch, lest the lateral pressure of the great arches should by oversetting their piers, bring the whole into ruin; they therefore suggest that it must be remedied by the following artificial means.

To insert a strong spring arch or a keystone, diagonally from the lower part of the base of the south pier, to the upper part of the base of the abutment wall, by which means (as a brace in timber work) the over pressure upon the foundation of the abutment wall will be discharged upon that of the pier, and thereby the dependance made upon the two together. They proceed then to take down the abutment wall, to a proper height below the crown of the arch, and to cap it with some courses of large hewn stone, firmly bonded together with chain bars, so as to prevent any further separation of the abutment wall, and upon this cap as a basis to raise a wall of a sufficient height; to spring a fresh arch over the former, so as to occupy the whole space between the abutment wall and the next great arch, by which means the present arch will have nothing to do but to preserve the uniformity of the appearance, then to draw the fractured and disjointed stones to make all fair, and bond the whole together with chain bars in the securest manner.

To this proposition we must be candid enough to say, that if very carefully executed we must expect it to succeed; but we think ourselves equally obliged in justice to all concerned, to declare, that in our opinion it would be more eligible, and what we would attempt were the case our own, to rebuild the fractured arch, and as much of the abutment wall, as can be taken down with safety.

To prevent therefore the lateral pressure of the great arches from taking effect, we would place an additional row of shoars in a similar position to those now there, which we would step upon the next set off, on the abutment wall below the present, and insert them into the solid of the pier at about the height of the impost of the great arch, those shoars to be of whole timber, and to be so many in number, that the spaces will be only equal to the timbers. This being carefully done and well keyed home, we would take down the small arch, leaving as much of the soffite standing on the north side as will support itself without

a center,

■ center, and as much of the solid work above as this will support, then taking down the abutment wall within two courses of the base, we would lay on two string courses to be of asfler within and without and strongly bonded together with chain bars. Upon this as a fresh base the abutment wall is again to be raised to its proper height, and the arch sprung over as before, and then finished with an arch of relief as suggested by Messrs. Mylne. This method to the best of our opinion may be put in execution with perfect safety to the great arches, yet we cannot take upon us to say we can absolutely ensure it.

6th. Respecting the rebuilding of the fallen vaults there is the least difficulty of all, for if the walls of these vaults are raised so high that the crowns thereof do properly clear the road, we perfectly agree with Messrs. Mylne in opinion, that they will be attended with all possible security, as the cause of failure will then be taken away, that is, the great weight of earth above them, due attention being had to the state of the foundation.

7th. The walls of the south abutment so far as they were filled solid with earth, seem to stand perfectly sound and firm, and being of less height than the correspondent ones on the north side are the less in want of help, however for the sake of security, as a further addition of earth will be wanted there, Messrs. Mylne in like manner intend to strengthen them on both sides with external abutments, which we entirely approve.

We cannot help adding by way of relieving the apprehensions that may occur hereafter, that we do not expect these or any other methods that can be taken, will put the building in so equal a poise, but that from the compressibility of the matter some joints will appear (especially of the upper work) to open, as has happened to all large bridges consisting of several arches hitherto built, and probably will happen to all that will be built.

Thus we have endeavoured in the clearest and most candid manner we are able, to set forth the true state of this work, as it respects the contracting parties and the public, and we do not doubt, that notwithstanding the accident that has happened, the reparation will be attended to with such diligence and care, that the work itself will remain a lasting monument to posterity.

Edinburgh,
22d August 1769.

J. SMEATON.
JOHN ADAM.
JOHN BAXTER.

To the Right Honorable the Lord Provost, Magistrates, and Bridge Committee of Edinburgh.

The REPORT of JOHN SMEATON, Engineer, upon the several Matters referred to him by the Minutes of the said Bridge Committee, the 17th January instant.

HAVING carefully considered the anonymous plan, together with the several matters transmitted to me by Mr. Stuart with the said minute, I find myself at a loss to come at an accurate judgement of the whole affair for want of the following materials, videlicet.

A true section of the ground for the whole length of the bridge from the high street to the opposite intended landing upon the natural ground.

A copy of the original design and contract thereupon.

An accurate drawing of what has been really executed in consequence thereof. And

A Report of the condition in which the foundation of the cross side walls of the south abutment arches, appeared when the rubbish was removed so far as to enable Mr. Mylne to build upon them as it is said; which materials seem necessary to compare with what is now laid before me. Nevertheless, that the accomplishment of this great necessary work may suffer no delay from me, from what I have seen and know of the affair, and from what I can collect from the several papers transmitted to me, I shall endeavour to deliver myself with all the precision I am able.

Having perused and re-perused all the papers above referred to, I find no reason to deviate in opinion from what is contained in the report of the 22d of August last, wherein I have the honour to be joined with Messrs. Adam and Baxter, but find many reasons to confirm me therein, and to more strongly enforce the necessity of the most material particulars therein contained.

Respecting the anonymous plan, it seems in many respects a delineation of what is pointed out in the before mentioned report, which, for the sake of distinction, I shall join in calling the Engineers report, the following particulars however excepted.

1st. He

■ center, and as much of the solid work above as this will support, then taking down the abutment wall within two courses of the base, we would lay on two string courses to be of ailer within and without and strongly bonded together with chain bars. Upon this as a fresh base the abutment wall is again to be raised to its proper height, and the arch sprung over as before, and then finished with an arch of relief as suggested by Messrs. Mylne. This method to the best of our opinion may be put in execution with perfect safety to the great arches, yet we cannot take upon us to say we can absolutely ensure it.

6th. Respecting the rebuilding of the fallen vaults there is the least difficulty of all, for if the walls of these vaults are raised so high that the crowns thereof do properly clear the road, we perfectly agree with Messrs. Mylne in opinion, that they will be attended with all possible security, as the cause of failure will then be taken away, that is, the great weight of earth above them, due attention being had to the state of the foundation.

7th. The walls of the south abutment so far as they were filled solid with earth, seem to stand perfectly sound and firm, and being of less height than the correspondent ones on the north side are the less in want of help, however for the sake of security, ■ ■ further addition of earth will be wanted there, Messrs. Mylne in like manner intend to strengthen them on both sides with external abutments, which we entirely approve.

We cannot help adding by way of relieving the apprehensions that may occur hereafter, that we do not expect these or any other methods that can be taken, will put the building in so equal a poise, but that from the compressibility of the matter some joints will appear (especially of the upper work) to open, as has happened to all large bridges consisting of several arches hitherto built, and probably will happen to all that will be built.

Thus we have endeavoured in the clearest and most candid manner we are able, to set forth the true state of this work, as it respects the contracting parties and the public, and we do not doubt, that notwithstanding the accident that has happened, the reparation will be attended to with such diligence and care, that the work itself will remain a lasting monument to posterity.

Edinburgh,
22d August 1769.

J. SMEATON.
JOHN ADAM.
JOHN BAXTER.

To the Right Honorable the Lord Provost, Magistrates, and Bridge Committee of Edinburgh.

The REPORT of JOHN SMEATON, Engineer, upon the several Matters referred to him by the Minutes of the said Bridge Committee, the 17th January instant.

HAVING carefully considered the anonymous plan, together with the several matters transmitted to me by Mr. Stuart with the said minute, I find myself at a loss to come at ■ accurate judgement ■ whole affair for want of the following materials, videlicet.

A true section of the ground for the whole length of the bridge from the high street to the opposite intended landing upon the natural ground.

A copy of the original design and contract thereupon.

An accurate drawing of what has been really executed in consequence thereof. And

A Report of the condition in which the foundation of the cross side walls of the south abutment arches, appeared when the rubbish was removed so far as to enable Mr. Mylne to build upon them as it is said; which materials seem necessary to compare with what is now laid before me. Nevertheless, that the accomplishment of this great necessary work may suffer no delay from me, from what I have seen and know of the affair, and from what I can collect from the several papers transmitted to me, I shall endeavour to deliver myself with all the precision I am able.

Having perused and re-perused all the papers above referred to, I find no reason to deviate in opinion from what is contained in the report of the 22d of August last, wherein I have the honour to be joined with Messrs. Adam and Baxter, but find many reasons to confirm me therein, and to more strongly enforce the necessity of the most material particulars therein contained.

Respecting the anonymous plan, it seems in many respects a delineation of what is pointed out in the before mentioned report, which, for the sake of distinction, I shall join in calling the Engineers report, the following particulars however excepted.

1st. He

1st. He proposes to build a division wall and to lay floors in the south abutment by way of tying the cross and side walls together, and to take down the north abutment, in order to rebuild it upon the same plan as the south.

2dly. He proposes to raise the building four feet higher than it was laid out for at the time of the accident, to fill up this space with earth or rubbish, and reduce this additional load by constructing hollow cylinders over the piers, which from the draft appear to be intended twenty feet diameter.

In regard to the matter contained in the first article, as the anonymous gentleman pretty strongly insinuates, that the public will not be satisfied with the judgment of those who have spent a great part of their lives in the study of the poise and strength of materials; as I expect the gentleman knows their mind, I hope they will be satisfied with what he has now proposed, and as Mr. Mylne makes no objection to the execution thereof, I shall not object it, as it can do no harm. I only desire to say, that I think it unnecessary, especially in works to be carried up anew. Had he proposed to have run a division wall through the north abutment, and to have only taken down the walls below the spring of the present arches, in order to have tied them afresh together by good bond stones, and then to raise them high enough to turn fresh arches at a proper height, instead of turning fresh ones over the present as proposed by the engineers, he would have made a judicious improvement; to take them down to the ground can do no more, and to take them up entirely, after having been compressed with double the weight they will again be subject to, in order to lay them on new bearings, may render them obnoxious to cracks and sets as before.

To what is contained in the second article, namely, the raising the whole building four feet higher, I entirely object: for though this in his opinion may relieve the fears of the public, it will greatly increase mine.

From what appeared on view, it was my opinion, and seemed that of the gentlemen with me, that the piers of the great arches had complained of the load of earth that then had been upon them, but not in such a degree as to be absolutely unsafe, and therefore could they be lightened there could be no danger of their failing. What Messrs. Mylne's proposed concerning the shaving of two feet from the whole surface, might possibly be understood in different senses by the gentlemen to whom delivered; and though we concurred in the same words, it is possible we might have different ideas affixed thereto, (such is the state of manhood); I did not for my part understand that Messrs. Mylne's proposed to shave off two feet from the body of the earth then upon the bridge, which if I remember

remember right, was about that quantity below the height, which would have been necessary to have completed his then plan; but to shave off two feet from the plan as proposed in its completion; for had I understood that he meant to reduce the earth upon the bridge, then two feet too low, to be two feet lower, the relative heights of the parapets and declivity would have been four feet, and not two feet greater as observed in the report. In short, my opinion, and I understood that of those with me was, that the piers of the great arches could not safely carry a greater load than then lay upon them, and with some reduction would be safe; with this view the 4th article was drawn up, which I desire in this place may be read.

It is said in remarks upon the anonymous plan, article 5th, that by Mr. Mylne's plan, the top of the cornice or level of the causeway, was to be nine feet above the soffit of the arches. The ground was then, or was to be, reduced by shaving to seven feet above the soffits; the anonymous plan adds to Mr. Mylne's plan four feet, that is 13 feet above the soffits, and is so delineated in the plan before me; consequently the anonymous plan proposed to lay upon the bridge six feet additional height and weight more than was thought prudent by the engineers' report, amounting to upwards of 4000 tons, upon the bases of the four detached piers, and I beg leave to observe, that 20 feet cylinders, or the value thereof, are practicable over the piers, when the road is at the height of seven feet above the soffits, this 4000 tons is all sheer addition to the engineers' plan; some small deductions for the different height of the parapets above the road excepted.

In order to be more distinct upon this subject, we will consider the difference that will arise to one pier alone, supposing one of the piers supporting the centre arches, which will be subjected to the greatest pressure; it is evident, that one of the piers supports not only the matter above it, but one half of each adjoining arch, and the matter above them. Six feet addition will therefore lay on a load of 1200 tons upon the base of one of the centre piers more than by the engineers' plan, and 600 tons more than they have yet been loaded with, even after deducting the cylinders proposed; and 350 tons more after deducting the greatest cylinders practicable in the given dimensions: but without pursuing the anonymous plan any further, I will now take it up as acceded to by Mr. Mylne, and suppose it to be executed to the greatest advantage. Now according to the reduction proposed by Mr. Mylne, there still will be an addition of four feet to the engineers' plan, and though that height will yet admit of cylinders larger in diameter by two feet than marked out in the anonymous plan, yet the load on one of these piers will still be greater by 684 tons than by the engineers' plan, and greater by 86 tons than it ever yet has carried, that is, supposing the ground never made up within two feet of the top of the cornice. The bridge

bridge committee may, if they please, try this experiment; and I won't say it will not succeed; but I can by no means recommend it.

It remains therefore to point out how the bridge is to be made accessible in the most easy manner that present circumstances will allow, consistently with the reductions proposed in the report of the engineers.

From the eighth article of the explanation of the anonymous plan, it is said, *the building is raised four feet higher to make the line of declivity one in 16, as was originally intended, and to end at the breast of the south abutment*. At the plan before me makes a declivity of about 1 in 14½, and the remarker, article 10, observes, that to recover the lost height will require a rise of six feet ten inches; taking this granted it follows, that at the height assigned by the engineers there will be a loss of eight feet ten inches; now I find the length of the slope contained within the compass of the plan before me is about 360 feet, and from the tendency of the lines there seems to be about 106 feet wanting of the summit in the high street to complete the whole length: it will follow therefore that this addition of eight feet ten inches will reduce the slope from 1 in 16 to 1 in 12; and I beg leave to observe that in hilly countries, where the slopes in turnpike roads can be reduced so as not to exceed 1 in 12, they are esteemed fully to answer the intentions. The ascent of the arches over Westminster Bridge was originally laid out to be 1 in 20, but I apprehend from the eye, that the ascents at each end, are at least 1 in 12, and it is a kind of rule in these parts that in laying out roads and bridges, if the ascents do not exceed three inches per yard, they are no ways objectionable. The slope by me originally laid out for the ascent of the west abutment of the bridge at Perth, is 1 in 12, and of this may be produced a multitude of examples. In fact, since the whole ascent between two given points must always remain the same, where the length of the declivity happens to be such, that horses in carriages cannot conveniently trot up, they may as well be reduced to 1 in 12, at which ascent they can conveniently walk and draw, because the length is less than if more sloping.

If the declivity marked out in the plan before me is to be adopted, then by extending the slope a little beyond the middle of the first great arch, this slope will cut the level marked out in the engineers' report; and to reconcile these two planes without so great a difference in the height of the parapets, as would be the case if the top of the parapets preserves it level to the south abutment, I would make no scruple (were the case my own, and I were left to do what I pleased) to make the parapet conform to the road; but yet, I would not suffer them to meet in an angle, but reconcile them by a curve, so that the masonry

should

should seem gradually to conform itself to the ground it stands upon, and to that to which it is to be connected. The line of the top of the parapet is, according to this idea, marked out with red ink upon the plan*; the height of the road being also distinguished by a dotted line, either of the above methods, ■ they leave the *stability* of the bridge *without* ■ *doubt*, I think far preferable to any increase of its load, which in raising it can scarcely be avoided; so far from it, I would sooner propose to reduce it two feet more, that is to five feet thickness from the soffit of the arch to the top of the road; for, as I understand the penstones are from three feet high, there will still be a two feet cover, which, in my opinion, is amply sufficient, and even then, the slope from the south abutment will meet the horizontal plane before you are over the nearest pier of the center arch, and this plane will still be higher, though not much above the level of the point from whence the north abutment commences; and in my opinion the reducing the whole to one level after the first descent will have ■ better effect upon the eye than by a second angle bent the contrary way, in leaving the breast-wall of the north abutment, and will at the same time greatly relieve the vaults and retaining walls thereof.

I beg leave further to add, respecting the fractured arch on the south side, that I have no reason to differ from what is contained in the fifth article of the engineers' report. I think it may be repaired as Messrs. Mylnes have proposed, and I think it may be taken down and rebuilt with safety, and this I advise. I think the abutment wall may be effectually tied together, if taken down within two courses of the base, and that the preference of taking it down to the surface of the base can amount to little more in reality than taking away the remaining *appearance* of a crack, as the foundation will then remain fractured as it is, nor do I think it any ways eligible to take it quite up, for since the pressure it has had has undoubtedly brought all to a solid bearing, the taking it up and laying it upon new bearings, may produce greater derangements than it is intended to cure; lastly, I don't think the method of shoaring the great arches proposed, by timbers to be laid horizontally, is so efficacious against a sett of the great arch as the shoars recommended in the engineers' report. At the same time it is my opinion that either will do, and that neither is absolutely necessary: my reasons for them were rather to make that sure, which might easily be done, and to relieve the apprehensions of Messrs. Mylnes and the public, than any absolute necessity: on the contrary, I am of opinion, that the great arches would stand upon their own legs, *if unloaded of the earth upon them*: but as there is no necessity to run this risque, I do not advise the experiment to be tried.

J. SMEATON.

Ausborne,
27th January 1770.

■ This plan is not among the papers of Mr. Smeaton. Ed.

EDINBURGH WATER SERVICE.

The REPORT of JOHN SMEATON, Engineer, upon the State and Improvement of the Water Service of the City of Edinburgh.

THE supply of the city of Edinburgh with a sufficiency of good water being a matter of very great concern, and the Town Council of the said City having done me the honour to consult me upon the proposed improvements relative to this business, when I was last at Edinburgh, in the month of September, I have been solicitous that no investigation or enquiry should be neglected which might contribute to the perfection and certainty of this great object; and this I was more induced to do, finding that Baillie Cleghorn, who attended my viewing of the premises, had taken this matter very properly up, and needed only that kind of information which might be expected from me professionally, and which my particular study and application to this branch of hydraulicks, I trust, enable me to furnish.

Since the view above mentioned, which was upon the 6th of September last, I have received from him not only copies of the two memorials delivered by him to the Town Council, and of the register from April 1778 to March 1779 inclusive, and of the necessary printed papers, but also a plan and section of the Hareburn and Swanstone pipe from the spring to the Comistone reservoir, which I suggested as necessary to be taken, in order to come at proper data for the calculation of what may and ought to be done there; so that the matter being now fully before me, I shall do myself the honour of laying before the Town Council the result of my calculations and animadversions on this occasion.

It is to be observed, that a deficiency of water in the city of Edinburgh arises from two causes, first, from a failure of springs collected into the reservoir at Comingston, in the dry months of the year, and, secondly, from an incapacity of the main pipe of conduct, which conveys it from thence to the town's reservoir on the Castle Hill, to bring a sufficiency to answer the demands of the increased number of houses and inhabitants, who are generally wanting the winter season, when there is the greatest plenty at Comistone, if the pipe would but bring it. Doubtless, the first and most obvious expedient would be that of enlarging the main pipe; but this being a work of great expense and not soon effected, Baillie Cleghorn very judiciously considered that an increase of declivity, or total fall between the reservoirs, by increasing the velocity of the water's current, would in event bring more water as certainly as an enlargement of the pipe; he therefore proposed and

executed

executed what immediately admitted of being done, that is, to let in the water issuing from the main pipe into the reservoir at Castle Hill, at the bottom instead of the top, as it used to be, by which empty an addition of fall is gained equal to the depth of the reservoir, which being $7\frac{1}{2}$ feet, this added to 44, the total fall or difference of level between the two reservoirs (in a length of $2\frac{1}{2}$ miles), making together $51\frac{1}{2}$ feet, instead of 44, has so far increased its velocity, when there is little water in, there is little water in the Castle Hill reservoir, and when it is most wanted by the town, that as it appears by the register it is now capable of discharging 200 pints per minute, instead of 160, a difference equal to one full fourth of its former produce, and amounting to the additional quantity of 112 tons per day, which alone is a very valuable acquisition.

Observing the good effects of this operation, he has proposed by way of still further increasing the quantity of water to be brought by the same pipe without enlargement of its dimensions, to construct a new reservoir in the garden of Heriot Hospital, which being upon a level with the street of the Trone church, is consequently above the greatest part of the city, new town, and suburbs of Edinburgh, at the same time that it is 119 feet below the level of the reservoir at Comistone, instead of $51\frac{1}{2}$, which is the present greatest fall to the Castle Hill reservoir; consequently if those parts of the town that cannot be commanded by the lower reservoir, are continued to be served from the Castle Hill, a part of the 24 hours may be appropriated to collect water in the Castle Hill reservoir, sufficient for 24 hours supply for that part of the town, that district being still dependent on the same, and a much greater portion of the 24 hours can then be applied to collect water into the new reservoir, which, from the greater fall, will be delivered at a much greater rate, and much more water will be brought for the 24 hours supply of the rest of the town, than if it were all obliged to ascend to the Castle Hill reservoir; this he has proved experimentally by observing that the discharge of water at the cleansing cock in the grass market, lying 170 feet below the level of Comistone reservoir, was 160 pints per minute more than would have been discharged at the Castle Hill reservoir, though the orifice by which it was discharged was much less than the bore of the pipe, and he also further confirmed this, by trying the discharge at the second cleansing, each above a mile from Comistone, which though only 131 feet below the level of the said reservoir, yet discharged 200 pints per minute more than could be discharged at the Castle Hill, and it is to be presumed, that this cock also was less than the bore of the main pipe.

This proposition for a new reservoir at Heriot's Hospital, however judicious and effectual for bringing an additional quantity of water from Comistone when there is a surpluse there, yet when from the other cause, a failure of the springs, there is not more water than the present capacity of the pipe will convey, no more can be had; and though this chiefly

chiefly happens (as appears from the register) in the months of August, September, and October, when most families are out of town, yet as the present surplufage in May, June, and July does not appear considerable, in every event an additional supply at all times is a thing most desirable; and this Baillie Cleghorn has not only in part done, by opening springs and preventing unnecessary wastes before the arrival of the water from the several sources at Comistone; but having observed that a considerable quantity of water furnished by the Hareburn runs continually waste that cannot be received into the Swanstone pipe, and thereby conveyed to Comistone, which the 12th of August last, in a dry season, amounted to no less than 160 pints per minute more than was received into the pipe, has proposed to lay a new pipe, of a sufficient bore to convey the whole water of this burn in dry seasons as above, which he proposes to be of four inches, in aid of the other, and to avoid an overload of expense, he proposes it to be of wood.

These, I think, are the propositions laid before me. On viewing the premises I observed that the whole of the Hareburn might be taken up upon considerably higher ground than the Swanstone well, where it is now taken in; and being informed that the water furnished by the Swanstone spring itself is but an inconsiderable part of the water now conveyed by the Swanstone pipe, (which, at the utmost, appears from the register to be 76 pints per minute) it occurred to me that it might possibly come out from a proper calculation, that by lengthening the Swanstone pipe to the rise so as to take in the water of the Hareburn with that of the next spring above, would add so much to the fall (leaving out the Swanstone spring, as inconsiderable in proportion to the acquisition of the Hareburn) that the present pipe might then be able to convey the whole of the Hareburn water; but this could only be known by a survey of the length and profile, shewing the difference of level that there now is and may be further obtained in the course of this pipe. From the survey and level now before me, it appears that the fall in the pipe itself is much greater, and the additional fall to be gained to the next spring above much less than I expected; I shall therefore insert the following table, shewing the result of the different calculations I have made, chequed with the water actually given in pints per minute, where opportunity has offered; from whence may be inferred what degree of aid it is to be given to those where that opportunity has not offered.

For in the present length of the Swanstone pipe, viz. 2145 yards, there is no less than 168 feet of fall; and to get 40 feet of fall in addition we must increase the length 280 yards more, which, though giving upon the whole a greater power, yet is not sufficient increase to carry the necessary addition of the Hareburn water.

TABLE of RESULTS of WATER given and expected by Calculation on different WATER-PIPES belonging to the City of *Edinburgh*.

No.	Pipe calculated upon.	Bore	Length in Feet.	Fall in Feet.	Water expended by calculation.	Water given in Measure.	Difference.	Proportional Difference.
1.	Swanstone pipe as it now lies	2½	6435	168	116	76	40	½
2.	Do. with 280 yards to the spring above, & 140 feet additional rise	—	7275	208	122	—	—	—
3.	For the first 1000 yards, in which 30 feet	—	3000	30	72	—	—	—
4.	Do. for the principal descent, ex. of the first 1000 yards from the Swanstone well	—	3435	138	145	—	—	—
5.	A new pipe to convey the water from the present Swanstone well to Comistone reservoir	—	6435	168	236	—	—	—
6.	The main pipe from Comistone to the Castle Hill, before the alteration	4½	14637	44	159	160	1	1½
7.	Do. after the alteration	—	—	51½	173	200	27	½
8.	The main pipe water drawn at the Grass-market cleaning cock	—	13985	170½	346	360	14	¼
9.	The main pipe water drawn at the second clearing cock	—	5359	131	492	400	92	⅓
10.	The main pipe water drawn at a reservoir in Heriot's Hospital garden	—	13550	110	280	—	—	—

The deficiency of No. 9. in giving ⅓ less than it ought to have done by calculation was, doubtless, owing to the bore of the cock not being large enough to let the water freely out, and it may be inferred in respect to No. 8. that it was sufficiently large; but in regard to No. 1. it appears that the Swanstone pipe is considerably defective in giving its proper quantity, which may arise from an injudicious use of its air-cocks, or their not being air-tight when closed, or from the pipe itself not being air-tight; for if any of the cocks are supposed to be open, or to take in air as much as the pipe will want, then it appears from No. 3. that the Swanstone pipe gives as much water as by calculation under these circumstances it ought to do, or the deficiency may arise from its not being fully 2½ inches as reported, for if really only 2¼ it gives nearly its proper quantity. It does not however appear, that, if rendered perfect, it is likely to convey the waters of Swanstone spring and Hareburn, viz. 76 pints per minute that it now brings, together with 160 pints in addition, in the whole 236 pints, but it appears from No. 4. that a pipe of 3½ inches bore would fully answer the end.

Doubtless a wooden pipe of four inches in aid of the present would be more than enough, nor can there be any sufficient objection to the use thereof; but as all the rest of the water-

water-pipes belonging to this work are of lead, which for this purpose is not only the sweetest but most durable, it appears to me likely that if the present $2\frac{1}{2}$ pipe be taken up and recast of $3\frac{1}{2}$ inches, the addition of labour and weight of lead may be done for nearly the same expense as the laying a wooden pipe.

The weight of a molded pipe of $2\frac{1}{2}$ inches bore is seldom less than 30lb. to the yard, or more than 36; in the present case I suppose the medium weight, 33lb. per yard; this, for the length of 2145 yards, will amount to 622 cwt.

It appears from Mr. Leslie's section, that this pipe is almost upon a continual descent, there being no rise but from a point which is 584 yards from the spring head to another at a thousand; in which space the pipe rises 26 feet perpendicular, so that the pipe being constantly open at both ends this is the only part that sustains the pressure of a perpendicular column; for were the pipe laid upon one continual descent, and both ends open, the water would lay no strain upon it, but run through it merely as it would through an open channel, and the pressure of 26 feet that particular part sustains is so inconsiderable that it may be laid out of the question, as it will be necessary to make the pipe stronger merely to preserve its figure from being pressed inwards than would be necessary to sustain the column of water tending to press it outwards.

The case of the main pipe to the Castle Hill is very different, for it appears from the general section, that from the Grass Market cleansing-cock to the top of the Castle Hill reservoir, whither it used to rise, is an ascent of $126\frac{1}{2}$ feet, and so much pressure of perpendicular column of water, that part of the pipe must suffer in crossing the bottom of the Grass Market.

For these reasons, the Swanstone pipe needs no other strength than what will be prudent to give it, to preserve its figure against the pressure of the earth, the accidental crossing of carriages, together with plows and animals over the ground; and for these purposes I look upon a $3\frac{1}{2}$ inch pipe as sufficiently guarded (it being carefully bedded and covered) if made of sheet lead turned and burnt, of the strength of 11lb. to the square foot, which is exactly $\frac{1}{16}$ of an inch in thickness, which method I also look upon as more safe from leakings than molded pipe.

A pipe of this construction will contain a foot superficies in a foot running, so that it will be the same weight as it is computed the present pipe is of, viz. 33lb. to the yard, so that the present pipe recast will make the new one, with the addition of so much lead as will make good the waste: and from a careful estimate, I find, that this pipe should be

recast, the waste made good, carriage to Edinburgh and out again included, for 3s. 9d. per yard, which, for 2,145 yards, amounts to the sum of 402l. 3s. 9d., whereas by a similar estimate I find, that an elm pipe of four inches bore, including carriage out, the sum of 360l. 11s. 3d. exclusive of the expense of opening and filling the ground, which I suppose to be nearly equal in both the cases; the difference, therefore, being no more than 41l. 12s. 6d. I apprehend will not be an object in the determination, and in case the recasting of the lead pipe is determined upon, I shall be ready to supply such further directions for the casting and laying of it, as shall enable it to produce the whole of the effect expected from it.

We come now to the proposition that relates to the erection of a reservoir in Heriot's Hospital Garden; and to give it some elevation and advantage, I have supposed it to be elevated nine feet above the ground, that is, the water to come in at 110 feet below the Comistone reservoir, at which depth may be expected to be got 280 pints per minute, as per No. 10.

It is laid down by Baillie Cleghorn, as a certainty drawn from experience, that when the water comes into the present reservoir, at the rate of 200 pints per minute, that this is sufficient to serve the city of Edinburgh well, that is to say, 288,000 pints in 24 hours. It must follow, that 288,000 pints in 24 hours issued from a reservoir in Heriot's garden, must serve every part of the town that can be served thereby very well.

Now 288,000 pints coming in at the rate of 280 pints per minute, will be received in 17 hours $8\frac{1}{2}$ minutes, there therefore will remain 6 hours $51\frac{1}{2}$ minutes for the main to run into the Castle Hill reservoir, which will still thereby be capable of serving nearly upon $\frac{7}{11}$ of the inhabitants as amply as they are now served, at the rate of 200 pints per minute. But if $\frac{7}{11}$ of the inhabitants are supplied from the Castle Hill reservoir, this will spare $\frac{4}{11}$ of the water brought daily into the new reservoir, to be distributed to the south side of the town and extended royalty, beyond what is supposed to be comprehended in the service of 200 pints per minute.

It therefore now only remains to fix the dimensions of the new reservoir in Heriot's garden, so that it may hold a quantity of water equal to the service laid down.

I take it for granted, that by far the greatest part of the water used in the city of Edinburgh is drawn in the compass of 14 hours per day, and consequently that this may be looked upon as the average time of the daily expenditure. Now if the water to be drawn from the new reservoir were to come in at the same rate it is drawn out, no reservoir would

would be necessary, but only a small cistern to receive it. But if that be taken out in 14 hours, that requires 17 hours $8\frac{1}{2}$ minutes to come in, then there will be required a reservoir capable of holding 3 hours $8\frac{1}{2}$ minutes water to begin with in the morning, so that after 14 hours draft upon it, the contents of the cistern, with what comes in during the time, will be ended with the close of the service each day.

But a reservoir that must contain 3 hours $8\frac{1}{2}$ minutes water, at the rate of 280 pints per minute, must contain 52,794 pints, which at $103\frac{4}{5}$ cube inches to the pint, will amount to $3159\frac{1}{10}$, say 3160 cube feet, and if we suppose five feet depth of water to be filled and emptied therefrom, then, if square, the side of the square will be 25 feet $1\frac{1}{2}$ inch, or any other equivalent dimensions, as for instance by 27, allowance being made in depth, suppose half a foot, to prevent its running over the brim, instead of the waste pipe, and what may be left at the bottom.

I would, therefore, suppose it convenient, according to this establishment, not to dispense any water from this reservoir before seven in the morning or after nine at night, but to let the water run from the main into the reservoir till 10 at night, then to turn it upon the Castle Hill till five o'clock in the morning, when being again drawn into the new reservoir by seven o'clock, it will have got three hours water ready to begin the day's service. Experience, however, of the wants of the inhabitants must ultimately regulate the matter; and though I have shown that on a supposition the wants of the inhabitants, that must necessarily be served from the Castle Hill, will be supplied by seven hours water from the main (but like the other to be distributed in 14 hours), that a reservoir of the dimensions given will be fully sufficient; yet there is nothing but the charge to prohibit its being made of any larger size, that shall be thought convenient, because that will always be a treasury of water to answer any sudden exigence, as in like manner will that at the Castle Hill, which ought always to be got and kept full whenever the supply from Comistone will admit thereof.

J. SMEATON.

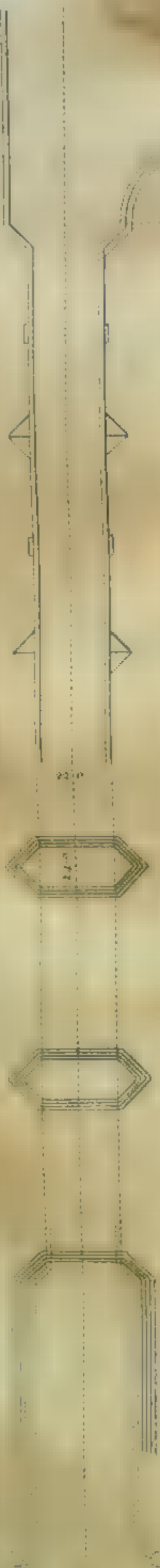
Ausborpe,
12th February 1780.

Elevation for a Bridge over the Tured at Coldstream.

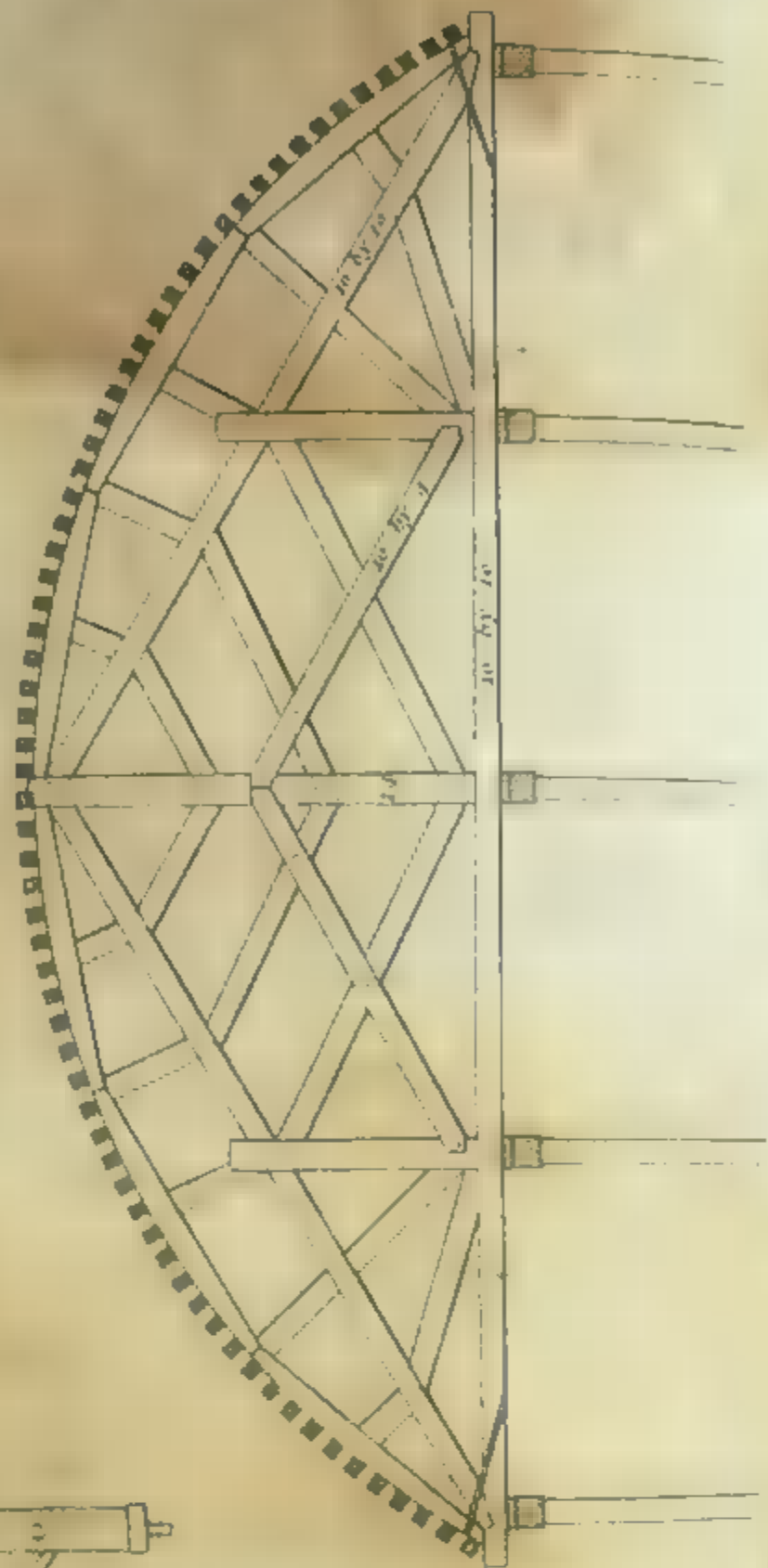


Scale of Feet.

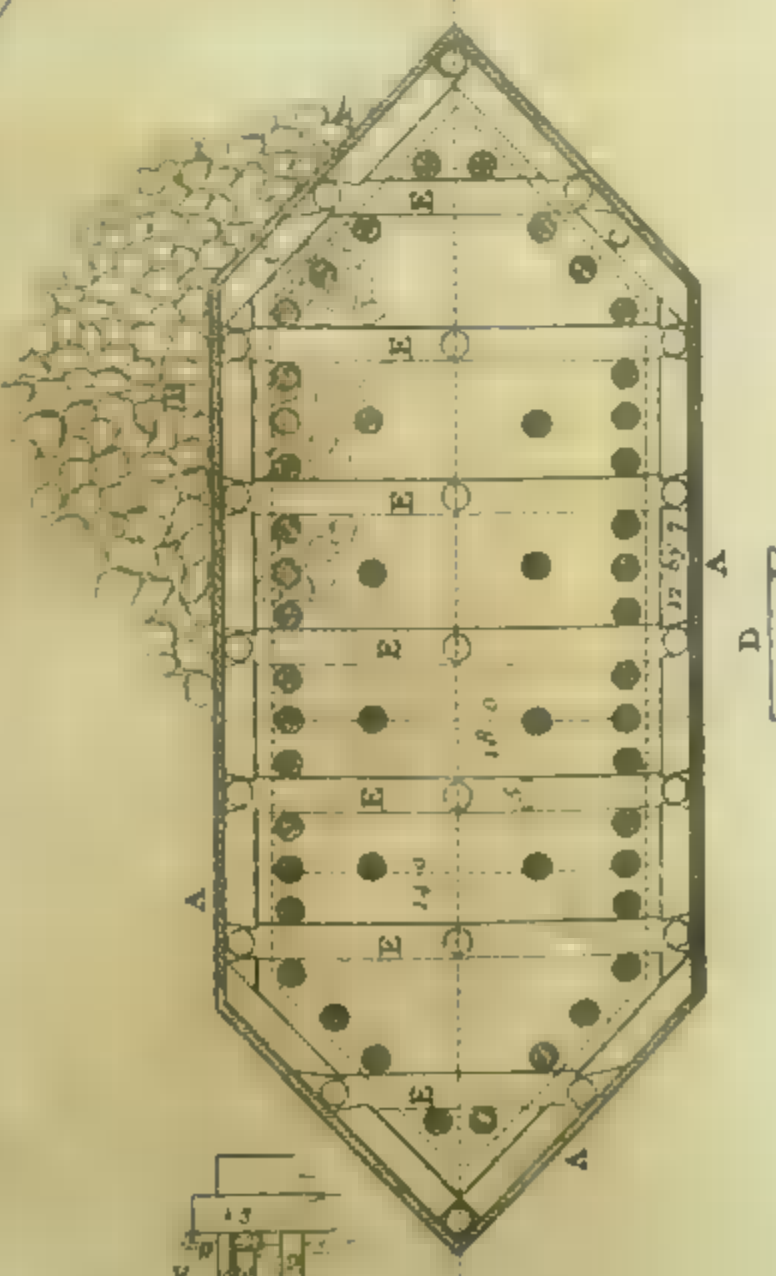
Plan



One of the 5 Ribs of the Centers.



Foundation for a Pier.



Scale of Feet.

COLDSTREAM BRIDGE.

(See Plate 10.)

To Mr. Pringle.

Sir,

Edinburgh, 31st July 1763.

This comes to acquaint you, that the Trustees of Coldstream Bridge having had a meeting, I laid before them the different plans, with the reasons thereof, when the low plan was unanimously chosen, as being sufficiently elegant, and at the same time better adapted to the funds, than either of those elevated to a semi-circle. According to this plan the side arches are 58 feet, and the two adjoining the centre 60 feet 5 inches, and the centre arch 60 feet 8 inches. They are all parts of the same circle, and the least arches are one-third, so that the others rise higher, as the additional span admits. The height of the piers above low water, including the impost of two feet, is 12 feet precisely; so that the shaft of the piers below low water must be raised 10 feet before the impost course comes on. I hope I shall be able to send the design for the centre, with the fair plan. I have satisfied the gentlemen relative to the foundation and method of proceeding.

Your's, &c.

J. SMEATON.

Mr. Foreman to Mr. Smeaton.

Sir,

I trouble you with this by order of a general meeting held this day for our bridge, who took into consideration the centre you proposed for throwing over the arches, and the one you saw Mr. Reid have a draft of, and which they had all seen before, and which you had no objection to, except that you thought a cheaper one might be made, that would answer the purpose. But on the wright's (carpenter's) estimate of both, yours proves to be the dearest by about eight pounds. Out of deference to your judgment, they would not, however, fix upon it till they had consulted you, and therefore ordered me to write to you, stating the different estimates, and begging to know if the centre proposed by you is preferable to the other, without regard to the difference of expense, for they choose to be determined by your opinion.

Your's, &c.

JOHN FOREMAN.

Coldstream,
March 27, 1764.

* This is the plan here given.

H h 2

To

To Mr. Foreman.

Austhorpe, 3d April 1764.

I am obliged by the confidence the trustees are pleased to honour me with, though in the present case there was no need for hesitation. The draft Mr. Reid shew'd being upon the same principle as the centres whereon the arches of Westminster Bridge were turned, there can be no doubt of its answering the end proposed, if justly and properly executed. But as I look upon those centres, when originally designed by the ingenious Mr. King, as intended to let the boats, &c. upon the river pass under the arches even while they were building, there was a necessity of making them hollow, and of distributing the supporting piles on the sides only; and on this account the middle part being geometrically supported, induced a necessity not only of stronger timbers, but of greater care in framing the bearings thereof, than if each part of the weight were more directly supported. It therefore occurred to me that when this was the case, not only slighter timbers would serve, but a much more simple and easy construction. What I had therefore in view was to distribute the supporters more equally under the burthen, preserving at the same time such a geometrical connection throughout the whole, that if any one pile, or row of piles, should settle, the incumbent weight would be supported by the rest.

With respect to the scantlings, I did not so much contrive how to do with the least quantity of timber, as how to cut it with the least waste; for as I took it for granted the centre would be constructed of East Country fir, I have set down the scantlings such as they usually are in whole balks, or cut in two lengthways, and as I think the pieces will suffer less by notchings in the middle intersection, and being cut into small pieces, it will remain of value for common building, after it has been done with as a centre. If therefore the value of the timber each way, after it has been done with for centres, has been taken into the account, and there still remains against me a balance of eight pounds, or even eight shillings, I have not that partiality for my own schemes, to prefer them where they are not applicable. Yet I must observe that had I a less opinion of your carpenter than I have, I should prefer my own for this reason, that as the construction is more obvious, and less exactness required in the handling, I should expect to get a good centre made by some in this way, that would make but bad work of the other.

Yours, &c.

J. SMEATON.

To Mr. Pringle.

Dear Sir,

Austhorpe, 27th June 1764.

I am sorry to find that the Tweed's gravel lies so very open; had it been wrecked up with sand and matter, as is most common, you would have completed the excavations with all ease and pleasure; but as it is common in water-works for things to turn out contrary

to expectation, change of circumstances requires change of measures, and nothing but time and patience can overcome the difficulties that often arise; and you may remember this as an undoubted maxim, that the less the business is put in a hurry, the sooner it will be done, provided the power is steadily applied towards the end proposed.

Piling foundations is generally a very tedious and expensive job; I was therefore desirous to avoid it by going down to the rock; but since the nature of the gravel makes the drainage likely to turn out so very expensive, of two evils it is best to choose the least; I have therefore enclosed a design for piling the foundation at its present depth, viz., as I understand it, three feet below the bed of the river. It is common in cases of this kind to lay down a grating and build upon it, without any piles at all; and this is certain, that so long as the matter keeps under the grating undisturbed, nothing bears weight better than gravel; but in so rapid a river as the Tweed, we are far from sure that the floods may not take away the gravel round the pier, below its present surface, and lay the grating bare; in which case the matter will move from under it, first near the sides, and then farther in, so as to let down the pier, and damage the arches. The common defence is to build starlings round the piers, terminating above low water; but as these considerably contract the water way, they are the cause of its acting more violently upon them towards their destruction.

In the enclosed design (see the plate), the main dependence is upon a sheet of plank piling AAAA, encircling the matter whereupon the pier is built, and which will hold it in, though the external gravel should by accident be taken away three feet below the top thereof, that is, six feet below the present bed of the river; but to prevent this accident, the excavated space between the sheet piling and the coffer dam is to be filled with rough rubble-stone B, as it comes out of the quarry; which, if any accident happens to it, may be repaired by an addition of the same kind of matter; but which can never happen after it is consolidated by the gravel washing into the same, unless the gravel without the boundary thereof should happen to be disturbed, and which, if filled even with the bed of the river, by throwing in rubble, will stir no more in the same place.

The sheet piling is to be driven as close to one another as may be, and the heads spiked to the frame CCC, and afterwards cut level with the surface thereof; the bottom of the plank piles being canted off as represented at D, will keep them close at the foot. This kind of plank piling when intended to hold water is grooved or dove-tailed one into another; but as these are only intended to retain the gravel, they will do plain, which will save a good deal of time and labour; for to drive into gravel, they ought to be of double the thickness if of fir; or else to be made of elm or beech to prevent their splitting, which

last mentioned woods I apprehend your situation could not readily afford. The piles represented under the frame CCC, are to be first drove to the level of the present bottom, and cut to a level, and the frame to be fastened down with pins thereupon. The tie-beams EE, &c. being dove-tailed to the outward frame, are chiefly intended to prevent the frame from flying outward by the pressure upon the matter within; those beams may be let in the outer frame about $3\frac{1}{2}$ inches; the other piles not represented under the frame, are to be drove after the frame is laid, and cut level with the upper side of the frame; then the whole of the frame and tie-beams are to be underpinned with rough stones; and the rest of the spaces to be rough paved and drove down with a heavy paviour's hammer, to be worked by two men, and the spaces filled with gravel; upon this foundation (which will be a kind of artificial rock) you are to build your masonry, but note, that the outside stones must all be headers, and long enough to reach upon the pile heads of the interior row, and also to project about nine inches beyond the sheet piling, and to be let down three inches thereupon, as shewn in the little sketch F, which will prevent the spikes from drawing or flying from the frame. In the course that brings you above water, you must lay in block stones in rows agreeably to the tie-beams, and thereby again cramp the work together from side to side. With respect to the interior piles, if care is taken to lay a found stone upon each pile head, this will answer better than planking; because it gives leave for every part of the work to be brought into contact upon the paving; so that the matter of every part of the area will come to an equal bearing, and save expense. This method being carefully and judiciously executed, will I think be little inferior to a foundation upon the rock itself, especially if the whole has sufficient time to settle before the arches are turned.

As your large piling engine will, I fear, be too heavy and cumbersome for this job, I would advise you to get two light ones made in the cat's-tail way, to be worked with 10 or 12 men each; the scantling of the stuff need not be above $3\frac{1}{2}$ inches, so that the men that work it, will easily move it; three, $3\frac{1}{2}$, or at most 4, cube feet of timber, will make as large a ram as those men can work, but it had better be under than over-weight; it is probable that the piles will require no shoes, or if they do, the bearing piles being sharpened to a flattish point about two inches broad, and covered with a piece of rolled metal, such as is made for cask hoops, turned up and nailed on each side like a saddle, and a broader one of milled iron plate put on in the same way upon the plank piles, is the whole we have used in the many thousand piles we have drove upon the Calder, which is in general a hard gravel mixed with stones. I would not advise you to drive longer than while you find the piles have got a firm seat upon the rock, lest by too much driving you cripple them, and render them useless.

The

The piles represented to be under the frame and tie-beams may be got near enough their places, by lines stretched from fixed points upon the coffer dam, without taking off the v. They may be driven down below the water's surface by setts, made as shewn at Z. The little iron pin at the bottom going into a hole in the pile head will keep it steady thereupon; the upper end should be convex, and the lower concave, to prevent splitting the pile, and two handles standing at right angles to each other will be better than one, ■ two men will thereby keep it more steady than one. This done, the water must be pumped out while they level the pile heads, and lay down the frame; then the rest of the piles may be drove by the side of the frame, by sets as before; a little practice will render the whole easy; lastly the water must be pumped out while the pile heads are levelled, the underpinning and setting is performed, and the pier brought above water; the stones being all ready prepared and got as convenient to the place as possible in the mean time; as to the rubbish on the outside, it may be thrown in at convenience, as well when the water is in ■ out; but must be done before the coffer dam is removed. I would advise to throw into the water for about 30 feet round the coffer dam, a light sprinkling of corn mould earth, this may possibly choak up the pores of the gravel, and ease you of part of the water; ■ much as will amount to three fourths of an inch thick, will be sufficient.

If you will please to let me know whether the rock be of such a nature that the piles may be driven five or six inches therein, I can contrive you an easier way of laying the next pier.

I am, Sir, your most humble servant,
J. SMEATON.

P. S. The piles that are represented round, need not be made so if your stuff is square; if you have not ■ sufficiency of stone for the outside of the first course, as above directed, you may intersperse headers and stretchers, but the more headers the better.

Austhorpe, 27th May 1765.

To Mr. Reid.

The making of a design for the caisson has not yet come into the course of business: however, that you may be proceeding to get proper stuff, as many two and a half inch deals as will reach round the base of the caisson by the sum of their breadth, and whose length is one foot more than the common depth of the water in the place where it is to be used, will make the covering of the sides; and so much Riga balk as reduced into three inch planks when laid cross and cross, so as to form a solid bottom of six inches thick, about one foot on every side larger than the base of the pier, will form the bottom of the caisson: other timber for braces, &c. will be wanted.

I am

last mentioned woods I apprehend your situation could not readily afford. The piles represented under the frame CCC, are to be first drove to the level of the present bottom, and cut to a level, and the frame to be fastened down with pins thereupon. The tie-beams EE, &c. being dove-tailed to the outward frame, are chiefly intended to prevent the frame from flying outward by the pressure upon the matter within; those beams may be let in the outer frame about $3\frac{1}{2}$ inches; the other piles not represented under the frame, are to be drove after the frame is laid, and cut level with the upper side of the frame; then the whole of the frame and tie-beams are to be underpinned with rough stones; and the rest of the spaces to be rough paved and drove down with a heavy paviour's hammer, to be worked by two men, and the spaces filled with gravel; upon this foundation (which will be a kind of artificial rock) you are to build your masonry, but note, that the outside stones must all be headers, and long enough to reach upon the pile heads of the interior row, and also to project about nine inches beyond the sheet piling, and to be let down three inches thereupon, as shewn in the little sketch F, which will prevent the spikes from drawing or flying from the frame. In the course that brings you above water, you must lay in block stones in rows agreeably to the tie-beams, and thereby again cramp the work together from side to side. With respect to the interior piles, if care is taken to lay a found stone upon each pile head, this will answer better than planking; because it gives leave for every part of the work to be brought into contact upon the paving; so that the matter of every part of the area will come to an equal bearing, and save expence. This method being carefully and judiciously executed, will I think be little inferior to a foundation upon the rock itself, especially if the whole has sufficient time to settle before the arches are turned.

As your large piling engine will, I fear, be too heavy and cumbersome for this job, I would advise you to get two light ones made in the cat's-tail way, to be worked with 10 or 12 men each; the scantling of the stuff need not be above $3\frac{1}{2}$ inches, so that the men that work it, will easily move it; three, $3\frac{1}{2}$, or at most 4, cube feet of timber, will make as large a ram as those men can work, but it had better be under than over-weight; it is probable that the piles will require no shoes, or if they do, the bearing piles being sharpened to a flattish point about two inches broad, and covered with a piece of rolled metal, such as is made for cask hoops, turned up and nailed on each side like a saddle, and a broader one of milled iron plate put on in the same way upon the plank piles, is the whole we have used in the many thousand piles we have drove upon the Calder, which is in general a hard gravel mixed with stones. I would not advise you to drive longer than while you find the piles have got a firm seat upon the rock, lest by too much driving you cripple them, and render them useless.

The

The piles represented to be under the frame and tie-beams may be got near enough their places, by lines stretched from fixed points upon the coffer dam, without taking off the v. . . . may be driven down below the water's surface by setts, made as shewn at Z, the little iron pin at the bottom going into a hole in the pile head will keep it steady thereupon; the upper end should be convex, and the lower concave, to prevent splitting the pile, and two handles standing at right angles to each other will be better than one, ■ two men will thereby keep it more steady than one. This done, the water must be pumped out while they level the pile heads, and lay down the frame; then the rest of the piles may be drove by the side of the frame, by sets as before; a little practice will render the whole easy; lastly the water must be pumped out while the pile heads are levelled, the underpinning a is performed, and the pier brought above water; the stones being all ready p and got as convenient to the place as possible in the mean time; as to the rubbish on the outside, it may be thrown in at convenience, as well when the water is in as out; but must be done before the coffer dam is removed. I would advise to throw into the water for about 30 feet round the coffer dam, ■ light sprinkling of corn mould earth, this may possibly choak up the pores of the gravel, and ease you of part of the water; ■ much as will amount to three fourths of an inch thick, will be sufficient.

If you will please to let me know whether the rock be of such a nature that the piles may be driven five or six inches therein, I can contrive you an easier way of laying the next pier.

I am, Sir, your most humble servant,
J. SMEATON.

P. S. The piles that are represented round, need not be made so if your stuff is square; if you have not a sufficiency of stone for the outside of the first course, as above directed, you may intersperse headers and stretchers, but the more headers the better.

To Mr. Reid.

Aulthorpe, 27th May 1765.

The making of a design for the caisson has not yet come into the course of business: however, that you may be proceeding to get proper stuff, as many two and a half inch deals as will reach round the base of the caisson by the sum of their breadth, and whose length is one foot more than the common depth of the water in the place where it is to be used, will make the covering of the sides; and so much Riga balk as reduced into three inch planks when laid cross and cross, so as to form a solid bottom of six inches thick, about one foot on every side larger than the base of the pier, will form the bottom of the caisson: other timber for braces, &c. will be wanted.

I am

I am much surpris'd at your account of the water rising three feet perpendicular on the west side of the bridge, more than on the east in time of floods, and think you must have made some mistake; but if the case be as you state, it will be highly necessary to take away the ground, and make a clear passage through the first arch, as well as to remove all the gravel thrown out of the foundation, and every other impediment to the free passage of the water: and also carefully to examine from time to time whether the rubble at the foot of the piled piers keeps its place without derangement; if not, timely to renew the same with heavier stones, or by extending the quantity. But I do not apprehend this need be done till you find some call for it.

Your's, &c.

J. SMEATON.

From Mr. Pringle.

Lees, November 22, 1766.

The Trustees for Coldstream Bridge hearing that you have inspected it very narrowly, beg you will be so good as to let them have your opinion of it in writing; particularly if you are perfectly satisfied about the sufficiency of the work, and if you think it has been carried on with proper expedition and economy.

Do you approve of laying a gangway on each side for foot passengers? And is there gravel enough laid on for this winter, to protect the crown of the arches from the weight of any carriage whatever?

Your's, &c.

J. PRINGLE.

To Mr. Pringle.

Dear Sir,

Your favour of the 22d came to me at a time when I was so much engaged (and which has indeed been the case ever since I had the pleasure of seeing you at Coldstream), that I could not possibly give you a distinct answer to your questions concerning Coldstream Bridge sooner than the present; for of all things I cannot make time.

1st. As to the sufficiency of the work? In answer to this I can say with great pleasure and truth that I have not seen better, and in this respect I should have thought myself very happy if every design of mine had received equal justice in the execution; nor can I apprehend that any material part will be subject to failure in a very long course of years, provided that a little attention be paid to the two piers, that are founded on piles; to see that the surrounding rubble stones lie in their places; or if removed by the great rapidity of floods, to be replaced by others as soon as may be; it will be necessary to attend

attend to this point for some years, though it is what most probably may not ever happen; there being all the security in the case that can be.

2dly. As to the length of time? According to the account I have received, it was begun the 7th July, 1763, and opened for all kinds of carriages the 28th October, 1766. A space of time comprehending three years three months and three weeks. This bridge consists of five principal arches, which with the four intermediate piers extend $353\frac{1}{2}$ feet between the abutments; besides two abutment arches of 20 feet each; and including abutments, extends 568 feet in the whole, being in breadth, including parapets, 25 feet. I doubt not but a much greater quantity of stones may be put together in the same time upon the dry land, or in a situation not exposed to so many hazards: but it is considered that the River Tweed swells by rains and snows frequently 14 feet perpendicular, and comes down with great rapidity; so that the work could not be pursued with any tolerable prospect of safety more than six months in the year, and those frequently interrupted by sudden land floods as aforesaid; these things considered, I do not know whether there is any example of so great a work attended with the same difficulties that has been done in so small a time.

3dly. Respecting the economy that has been observed in the construction thereof, I think you informed me that the neat expense of building this bridge did not or would not when fully completed exceed 6000*l*. Things of this kind are best judged of by comparison; we have seen instances of bridges as long, as broad, and as high-built for a less sum; but either they have been built in a more gentle river, or their piers have not been laid so deep below the low water surface, or below the bed of the river; or they have been laid upon a more uniform stratum of matter, or less scrupulously secured, or they have been built with smaller stones, or less exactly put together; so that taking in the whole I believe there has been no example of any bridge being built for so small a sum where circumstances have been equal or similar: and it is much to the credit of Mr. Reid, the surveyor of this work, that every thing that has been tried has succeeded; and the whole has been done without loss of life or limb to any one concerned: nor does there appear any settlement, false bearing, or fissure in the whole work, save a very minute one but just discoverable in the common spandrell walling above one of the piers, or one side, and in the joining of the work of two different years, and this wholly occasioned by laying a weight of gravel in the spandrells of the arches that rest on this pier when none could be laid in an adjacent spandrell to balance it; the whole not worthy of mention, but to satisfy those who may have thought it of more importance than it really is.

So much as to the sufficiency of the work and the conduct thereof: you next enquire, Whether there is a sufficiency of gravel to protect the crown of the arches during this winter from the weight of any carriages whatever? I am told there is a thick layer of gravel above the crowns of the arches, and if so it is very sufficient; if it should happen to cut deep, which is not to be expected, the rutts should be occasionally filled: and I apprehend it would do very well if never filled higher; but for greater security it will be proper to make an addition as hereafter mentioned.

Lastly, You ask me if I approve of laying a gangway on each side for foot passengers? I think it will be very proper to cover the spandrell walls with tolerably thick scapelled flags or paving stones, which will not only be a coping for the spandrell walls, and thereby prevent the wet from soaking down into them, but at the same time make a walking path on each side, and as there will still be 16 or 17 feet clear, this will be very sufficient for the meeting of carriages: the gravel then may be made up within nine inches of the surface of the walking paths, and laid a little rounding in the middle like a turnpike road. N. B. It will be proper to lay a ribband of stone nine inches thick next the road, to prevent the grazing of the wheels, or else to make the flagging nine inches thick, especially on the outward side next the gravel. This I think, Sir, answers all your queries.

Your's, &c.

J. SMEATON.

To Lord Home.

My Lord,

Austhorpe, 5th September 1770.

The very day your letter is dated I was viewing the bridge at Kelso, and in my journey to Woolerhaughhead had passed within sight of Coldstream Bridge, and where I should with great readiness have called had I had intimation that any thing had been amiss with it. In my way north I passed over it in the beginning of July, but I heard nothing I did not enter into any particular examination; but observing the stones lying as usual upon the salient points up stream, I took it for granted all was right. It was at request I many times repeated to my late worthy friend Mr. Pringle, and to Mr. Reid; that great care should be taken for some years to maintain the rough stone work round the two piers founded on piles, and from time to time to repair the smallest derangement till the whole should become settled: and I am sorry to see that this, as well as many other public works, has been so cramped in the finishing, that many essential things are left incomplete; and that it is not left worth the while of the person who has had the principal hand in the execution, and who must be

be best able to see and judge, and apply timely remedies, to interest himself therein.

Something of the kind now wanted is always necessary to be applied in gravel bottoms, and the case is noways difficult if done with judgment: and no better method can be taken than what you have already done, that is to throw in large rough stones, so as to form a slope up against the bases of the piers, and when this is done, to throw a considerable quantity of gravel upon them, or small rubble, in order to wash into and fill up the chinks of the larger stones. The less this outwork is extended, beyond what is necessary to secure it a sufficient natural base, the better, as all obstruction to the free course of the river through the arches, is hurtful. It is possible that as the work will not be all of a piece, some of the stones may be deranged by the action of the flood, but those being made good again seldom fail a second time, unless it be occasioned by a failure in some other place. All piles and wood-work are to be avoided, as the failure of the wood proves sooner or later a failure in the stones. The piles and boards there are the remains of the coffer dams, which it was then thought not prudent totally to eradicate, for fear of disturbing the gravel; but now that the rapidity of the flood has, I apprehend, taken away the surrounding gravel, and let down the wood-work, and thereby sapped and taken away the gravel from under the stones, the latter must necessarily go down; let therefore the whole be made up with rough stones, and as they can no more be sapped by the running away of the gravel from underneath them, you will find they will lie, and this the better, if those which can be laid by hand are so disposed as to lean down stream, as I formerly directed; and if it be found, that after a great flood the stuff to be laid upon the larger has disappeared, partly by washing into the interstices, and partly by washing away, it must be renewed till the interstices appear filled. It perhaps may be a question, as I expect it is only some part of the surrounding works that has suffered, whether those which have not failed should remain till they do, and then be made up in the same manner as before directed, or whether the piles should be now drawn, and the whole made up at once? But this is a matter which, without inspection, or the Report of Mr. Reid, setting forth the condition thereof, I am not enabled to decide upon. But this I am clear in, that if this business be carefully and properly performed, after all dependence on the wood-work is gone, and such derangements as may happen in the course of two or three years repaired, till the whole comes to a bearing, this part of the work will last for ages, and in case of any future misfortune can always be made good in the same way. I beg leave to observe that round stones will not do; rough stones from the quarry are best, the rougher they are the better.

In regard to forming a dam below the bridge, it is in this place totally unnecessary; the piles on which the piers rest are considerably below the water's surface in the state of the river, the work mentioned would be still necessary, and as much as would do the work in the way I mentioned four times over.

I am, &c.

J. SMEATON.

To the same.

My Lord,

Austhorpe, 16th August 1781.

I have been informed by a friend who passed over Coldstream Bridge last month, when the water of the Tweed was remarkable, that he observed the rubble laid for the defence of the piers to be much ruffled, a considerable part taken away, and left in the Tweed about forty or fifty yards below the bridge, and that in his opinion the rubble that had been laid, was too small and thin.

On this occasion, if any thing be necessary to be added to my letter of the 5th September 1770, it is, that I would recommend the rubble slope against the piers to extend thirty feet up stream above the salient points; and if a bank or shoal of rubble were made about thirty or forty yards down stream, the place where the present rubble is carried to, it would greatly tend to keep the defences about the piers in their place: and as this bank or shoal need not be raised so high as one foot below the surface of the water, in the ordinary state of the river, there can be no objection on account of the salmon fisheries; it should be a competent breadth at the top to resist the action of the floods in passing over it.

From what has happened, I am apt to think with my friend, that the rubble made use of has been too small. As he is not a man of my profession he may be mistaken, yet as he is of a general good judgment of things, I could not omit giving you this intimation for the public service, as Your Lordship had formerly honoured me with your correspondence on this subject. It was the original intention to build all the piers upon the rock; but Mr. Pringle finding the expense of pumping run very high, begged that the two piers in question might, if possible, be founded on the stratum of gravel which laid above the rock; which having been gradually worn away by the action of the floods, has occasioned the derangements that have since happened to the defences; which, however, being carefully attended to and kept up, the piers will rest with equal solidity upon the central matter as at first.

I am, &c.

J. SMEATON.

REPORT of ROBERT REID on the State of Coldstream Bridge.

To the Honourable the Trustees, appointed by Act of Parliament, for the Roads and Bridges in Berwickshire.

It evidently appears from experience, that the securing of the foundation of the piers of Coldstream Bridge is an annual expense notwithstanding all the vigilance and care of the trustees living near it, the expense is continually increasing. The reason is obvious; a great many of the guard piles are gone that formerly secured the rubble stones which were laid about the foundation of the end piers. And immediately after the great flood in the year 1782, they were obliged to lay a considerable quantity of large stones, which exceeded the limit allotted to them, which was ten feet from the piers which these guard piles pointed out. This being the case, the water is somewhat confined in its passage, and when it begins to rise it runs with such rapidity that it has thrown out the gravel from between those two piers founded upon wood, in great quantities, eastward from the tails of the piers. In some parts it has gone the depth of four feet, at other parts eight feet, and five feet; and if it should continue to work at that rate, it will bring out the gravel from between the piers, and leave these two piers standing upon stilts; and may be attended with bad consequences.

The question will now stand, how this is to be remedied? This I have pointed out to be by a dam-head, with a row of piles through the river, and a quantity of stones on each side of them, about 100 feet or thereabouts below the bridge; and whatever gravel stones, or other stuff the river brings, it will leave it there, and so go on till it has raised it as high as the dam-head, and in place of taking away any thing from the foundation, will be constantly laying to it; which must secure your foundation as long as the dam-head stands, the piles being in the middle of it, will secure it a long time.

Perhaps some objections may be made about the salmon fishing: to obviate these, there will be some openings left at proper distances for the passage of the fish.

Now this method I am perfectly sure of being effectual, as I helped to put one of these dam-heads into execution, at a bridge built by the Government over the river Tay, in the year 1735, and has been the safety of that bridge ever since. Before the mason work was perfectly finished, the river was making whirlpools at the tail of the pier; and after observing

In regard to forming a dam below the bridge, it is in this place totally unnecessary - the piles on which the piers rest are considerably below the water's surface in the state of the river, the work mentioned would be still necessary, and as much as would do the work in the way I mentioned four times over.

I am, &c.

J. SMEATON.

To the same.

My Lord,

Austhorpe, 16th August 1781.

I have been informed by a friend who passed over Coldstream Bridge last month, when the water of the Tweed was remarkable, that he observed the rubble laid for the defence of the piers to be much ruffled, and a considerable part taken away, and left in the Tweed about forty or fifty yards below the bridge, and that in his opinion the rubble that had been laid, was too small and thin.

On this occasion, if any thing be necessary to be added to my letter of the 5th September 1770, it is, that I would recommend the rubble slope against the piers to extend thirty feet up stream above the salient points; and if a bank or shoal of rubble were made about thirty or forty yards down stream, the place where the present rubble is carried to, it would greatly tend to keep the defences about the piers in their place: and as this bank or shoal need not be raised so high as one foot below the surface of the water, in the ordinary state of the river, there can be no objection on account of the salmon fisheries; it should be a competent breadth at the top to resist the action of the floods in passing over it.

From what has happened, I am apt to think with my friend, that the rubble made use of has been too small. As he is not a man of my profession he may be mistaken, yet as he is of a general good judgment of things, I could not omit giving you this intimation for the public service, as Your Lordship had formerly honoured me with your correspondence on this subject. It was the original intention to build all the piers upon the rock; but Mr. Pringle finding the expense of pumping run very high, begged that the two piers in question might, if possible, be founded on the stratum of gravel which laid above the rock; which having been gradually worn away by the action of the floods, has occasioned the derangements that have since happened to the defences; which, however, being carefully attended to and kept up, the piers will rest with equal solidity upon the central matter as at first.

I am, &c.

J. SMEATON.

REPORT of ROBERT REID on the State of Coldstream Bridge.

To the Honourable the Trustees, appointed by Act of Parliament, for the Roads and Bridges in Berwickshire.

IT evidently appears from experience, that the securing of the foundation of the piers of Coldstream Bridge is an annual expense notwithstanding all the vigilance and care of the trustees living near it, the expense is continually increasing. The reason is obvious; a great many of the guard piles are gone that formerly secured the rubble stones which were laid about the foundation of the end piers. And immediately after the great flood in the year 1782, they were obliged to lay a considerable quantity of large stones, which exceeded the limit allotted to them, which was ten feet from the piers which these guard piles pointed out. This being the case, the water is somewhat confined in its passage, and when it begins to rise it runs with such rapidity that it has thrown out the gravel from between those two piers founded upon wood, in great quantities, eastward from the tails of the piers. In some parts it has gone the depth of four feet, at other parts eight feet, and five feet; and if it should continue to work at that rate, it will bring out the gravel from between the piers, and leave these two piers standing upon stilts; and may be attended with bad consequences.

The question will now stand, how this is to be remedied? This I have pointed out to be by a dam-head, with a row of piles through the river, and a quantity of stones on each side of them, about 100 feet or thereabouts below the bridge; and whatever gravel stones, or other stuff the river brings, it will leave it there, and so go on till it has raised it as high as the dam-head, and in place of taking away any thing from the foundation, will be constantly laying to it; which must secure your foundation as long as the dam-head stands, the piles being in the middle of it, will secure it a long time.

Perhaps some objections may be made about the salmon fishing: to obviate these, there will be some openings left at proper distances for the passage of the fish.

Now this method I am perfectly sure of being effectual, as I helped to put one of these dam-heads into execution, at a bridge built by the Government over the river Tay, in the year 1735, and has been the safety of that bridge ever since. Before the mason work was perfectly finished, the river was making whirlpools at the tail of the pier; and after observing

observing that, all hands went to work to make the dam-head, which remains there to this day.

Another thing would require attention: as the south arch is for the most part of the year dry: formerly, when conversing with Mr. Smeaton about this bridge, he said it would be of great advantage that the water were brought through this arch, that it might give relief to the rest; and at the breaking of a frost there is commonly a mountain of ice lying in this arch, for want of water to carry it off.

ROBT. REID.

OPINION and DIRECTIONS of JOHN SMEATON, Engineer, for the Preservation of Coldstream Bridge, upon the Condition thereof, as stated in the Plan and Report of Mr. Robert Reid, dated October 19th 1784; transmitted to him in the Letter of Mr. James Gray of 3d May 1785.

To the Honourable the Trustees, appointed by Act of Parliament, for the Roads and Bridges in Berwickshire.

Sirs,

I observed, in my answer to the letter of my Lord Home in the year 1770, upon a derangement of a similar nature to the present, that I had many times repeated to my late worthy friend Mr. Pringle, of Lees, and also Mr. Reid the executive mason, that great care should be taken for some years to maintain the rough stone work round the two piers founded on piles; and from time to time to repair the smallest derangement, till the whole should become settled; that something of the kind then wanted, is always necessary to be applied in gravel bottoms; and that the case is no ways difficult, if done with judgment.

Since the year 1770, much greater and more violent floods have happened in all the northern rivers, than had been before pointed out to my experience: notwithstanding which, the same kind of directions having been punctually and carefully attended to at the bridge at Perth, no derangement has happened to produce any alarm.

In the year 1770, the speats of the Tweed had then in some measure destroyed the pile fences, originally driven to form the coffer dams for draining off the water while the piers were founding; and which it was thought improper to draw, for fear of disturbing

disturbing the surrounding gravel; the interior space being filled with rubble stones, to defend the piles immediately surrounding the piers within the said fences; but those giving way the stones contained within them. As it thus appeared that the pile work was not defensible by its own strength and stability, but that if reinstated, must be externally defended by the deposition of stones, I thought proper to advise, that the whole should be made up with rough stones; observing at the same time, that it was a matter of question which I could not decide without inspection, as the whole of the surrounding works might not have suffered together, whether those which had not failed should remain till they should fail, and then be made up in the same manner as those already directed; or that the whole piles should be drawn, and the whole made up at once.

It appears however from the present report, that by pursuing the methods then directed, the immediate foundations of the bridge have been so far preserved entire: but as the stones deposited for the safety of the foundation have hereby enlarged their base and slope, and in consequence somewhat straitened the water-way; and proving too stubborn to be removed by the rapidity of the stream, its action has been exerted in removing the gravel between the piers remaining undefended; and has pooled the holes, as particularly set forth and described in that report.

For my own part, I generally find it right to apply the strengthening plaister immediately to the weak part, and would begin the work by filling up every pooled part, even with those parts that remain of four feet deep: and in consideration of the increased rapidity of the floods within the last 15 years, I would advise all these fillings to be performed with stones of a larger size and weight than before directed; (that is to say) with stones from a ton to half a ton weight, and to chock in the interspaces with lesser stones, of such sizes as to make the whole a tolerably regular surface, extending as far as the pools exceed the depth of four feet; and then by way of further security, I would begin an artificial shoal to act in the nature of a dam, by laying a row of large stones across the river, at the distance of 100 feet below the bridge; and then depositing other stones above this, bringing the work forwards towards the bridge, and a little increasing in height, to the breadth of 30 feet; and so as to pen the water $1\frac{1}{2}$ or 2 feet deeper under the bridge at low still water, than it now is; and then to slope it upwards to the further breadth of 20 feet; making 50 feet in the whole breadth: this will make so easy a slope, that the salmon will make their way over it without interruption. I would make the lowest part of it, for the water's ordinary passage in dry times, in the place where it now is; but so near upon a level, that in the smallest speat it will flow over its whole length.

It appears on this occasion, when the work of the dam or shoal is established, as it will intersect the deep part of the river, that it will be proper to surround the pier that stands upon the rock, with a stratum of large stones chocked in with smaller, so as to form a bed or stratum of about two feet thick; and to a distance of six or seven feet from the base of the pier, where the rock is bare on the north side; and till it meets the stone of the rubble for defending the north side of the second pier: but at the down stream end to be continued till it meets the foot of the slope of the dam; by which means the aforesaid bed will be supported.

The use of the deposition of this bed round the pier upon the rock, is to preserve the floor of timber of six inches thick, that lies between the rock and the base of the stone work of the pier; for though it will not rot, yet the rapidity of the water running by, and acting upon its outward border, will doubtless in process of time corrode it, and may undermine the outside, so as to cause the outer to separate from the interior core. I do not imagine that any essential harm can as yet have happened from this cause; but it seems now time to set about such an expedient, to prevent future mischief.

When the work is brought to this situation, it will be proper to make the trial of another winter, in the course of which I would expect that part of the present bottom that does not now lie above four feet deep, being undefended, will be further pooled, and ought then as soon as perceived to be filled up even with the other, with heavy matter of the same kind; in consequence of which the whole will become capable of resisting the action of the water; and when by attention the whole of the soft places are made good, then it may be expected the bottom will remain untouched for ages. I cannot say I would advise the ultimate performance in this manner just now, because it will cost more to work away the gravel under water to a sufficient depth, than it will to fill the cavity when made; and if a stratum of sufficient weight and solidity were deposited over the present, it would too much obstruct the water-way.

In regard to the erection of a dam-head, without filling up the pools, though it is very possible the river may do it, yet it is very possible that it may not: and though this may be the case at Tay Bridge, this is but a single instance; and the operation of rivers is so very various according to situation, and I have seen so many dam-heads where the water has not filled them with gravel, that I cannot recommend it to depend upon this alone: whereas by filling the extra depth of the pools, and forming a shoal or dam of a lower kind, laying first a row of the largest stones by way of footing to the rest, no piles will be wanted, which are both expensive and tedious in the execution. An application of this same kind I recommended at Kelso Bridge, where notwithstanding a dam that had for years subsisted below, the piers were become so pooled and undermined, as to put the bridge

bridge in imminent danger: besides, in this mode of working, after the stones are won from the quarry, there will not be the need of a mason's tool to be laid upon them.

Furthermore, I apprehend it will be of utility and very proper that the south arch should be deepened to the same level as the pool when filled as already directed; and when this fresh surface pools further, to be treated in the same manner as the rest.

J. SMEATON.

Gray's Inn,
16th May 1785.

AT a Meeting of a Committee of the Trustees for the Berwickshire Turnpike Roads and Coldstream Bridge.

Coldstream, 9th August 1790.

Present — Eight Trustees, and Lord Swinton, Præses.

Inter alia, The following Memorial concerning the Bridge over the Tweed, near Coldstream, was laid before the Meeting:

About six years ago the river Tweed being very rapid, formed several pools or weels round the pillars or piers of the bridge, particularly the middle piers, which are founded upon wood, whereby it was thought the bridge was in considerable danger.

That thereupon Mr. Smeaton was consulted, and gave in a very full advice to the trustees, which was, in general, to build a dam-head or dike across the river, about seventy feet below the bridge, and of a height about two feet above low water mark.

That this was done accordingly; but some time after it was made, upon a suggestion of some of the trustees that if it was continued in that manner it would be an obstruction to the salmon getting up the river, a cut was made in the middle of the dam-dike, about seven feet wide, by way of making a free passage for the salmon.

Mr. Reid, mason, who is employed to take charge of the bridge, states that the gush of water passing through this opening makes a hollow in the channel of the river, both above and below the dam-dike, and particularly it sweeps away much of the gravel which the river brings down from above the bridge, and which would otherwise remain above the dike, secure its permanency, and prevent the blowing round the piers.

Mr. Reid farther informs the trustees, that in case a passage through the dike for the salmon coming up the river was necessary, it might perhaps be safe to fill up the present cut in the middle of the dam, and in place of it to make another opening at the south end of the dam-dike, and opposite the south arch, which is founded on a rock, and where the river runs upon or near the rock.

The trustees having considered the above representation from Mr. Reid, and having themselves visited the river, which happened then to be speat or flood, so that they could not see the effects of this gush of water either above or below the dam, they had various opinions concerning this matter; some thinking that there was no need of any opening at all for the passage of the fish, others thinking that the fish would be stopt except in speats; but all agreed in this, that the dam-like has been of the greatest advantage to the bridge, and that the preservation of the dam was the salvation of the bridge; it was fit to consult Mr. Smeaton what was necessary to be done in this matter, viz. whether, in his opinion, any opening was necessary for permitting the fish to pass up the river, and whether there was any danger from such an opening, and whether, if there was any necessity for it, it ought rather to be on the south side than in the middle? and that he would be pleased to communicate his advice and particular directions on the whole matter.

And in order that Mr. Smeaton may be the better enabled to give an opinion, they direct soundings to be made by Mr. Reid and Mr. Sharp, surveyor, in Coldstream, of the depth of the water both above and below the dam, and particularly in the channel of the opening; and to be sent to Mr. Smeaton along with the memorial. Extracted from the minutes of the trustees book.

JOHN TURNBULL, Clerk.

REPORT of JOHN SMEATON, Civil Engineer, upon the State and Condition of the Bridge of Coldstream, as stated in the Memorial to the Trustees of the Berwickshire Turnpike Roads, and Coldstream Bridge; the 9th August 1790.

When I had the honour of delivering my opinion upon the proper remedy for curing the defects then already felt, and further apprehended, in the foundation of Coldstream Bridge,

Bridge, about six years ago; wherein I advised a dam-dike to be built across the river about 70 feet below the bridge, and about two feet high at low water; I stated this height, in view that it should be no obstruction to the salmon getting up the river; having seen several instances of even upright dams of four feet high and upward, in salmon rivers, and which were not considered as an obstruction to the passage of the fish; as they are frequently seen to leap to a greater height than that. I could not therefore conceive that at two feet high, upon a sloping current, the least objection could arise, or be thought of. I am very happy to find that the expedient proposed and executed, has so effectually answered the intention.

Had I been consulted concerning the expediency or manner of the cut suggested to be made through the body of the dam, I should certainly have delivered it as my opinion, that none was in reality necessary: but if to satisfy the apprehensions of those who thought themselves interested in the fishery, the trustees should think something necessary, I should never have advised the execution to have been in the way it is suggested by this memorial to have been done; viz. *a cut of SEVEN feet wide in the MIDDLE of the dam-dike.*

I think it very lucky that this cut, being in the middle of the river, and consequently where in speats the principal current must be, has not by degrees grown wider and deeper, so as have destroyed the dam; and thereby have brought the bridge itself into that kind of danger which this work has been intended to guard against. I therefore recommend that the cut be filled up and made good, as at first; and in case, to save objections, an opening must be somewhere, it will, as Mr. Reid very properly suggests, be much the safest on the south side of the river, where the river runs the shallowest, and upon a rock. Indeed, I see no objection to remove the dam-dike so far entirely that the water may flow freely and without obstruction through the whole of the first arch of the bridge from the south; and opposite to the first pier begin the dam-dike, to rise gradually so as to come to its present height opposite to the second pier from the south. Indeed this slope will be formed in reality by the subtraction of the present matter, but yet it must be taken care to be caped with such new matter or weighty stones as are likely to lie and resist the current in speats.

J. SMEATON.

Gray's Inn,
26th November 1790.

NEWCASTLE BRIDGE.

REPORT of JOHN SMEATON, Engineer, concerning the State of that Part of Tyne Bridge, between Newcastle and Gateshead, which is in the County of Durham.

HAVING carefully inspected the south side of Tyne Bridge the 16th of September last at low water, I found it in a general state of disrepair: but as it has been originally ill built, I look upon it as impossible, after standing so many years, to render it perfectly sound, unless the whole was new built, which is not the present proposition; yet by occasional repairs seasonably applied, it may last for many years. I shall therefore take the arches in order, and confine myself to the pointing out of such things as more immediately call for assistance.

The first arch beginning from the south side, is in a great measure blocked up by cellars for convenience of the houses above, and has no current of water through it, when the low water is below the sterlings or jetees, as they are called, which surround all the piers in the manner of London Bridge: this arch seems at present to want no material repair.

The second arch has a passage between the jetees at low water. The aisling of the piers on both sides this arch wants repairs, many of them being loose, and some of them dropped out: the aisling on the north side appears worse than it really is, having been built originally bulging, at least so it seems to me.

The whole or greatest part of the arches of this bridge have been lined with ribs, as was customary formerly, with a view to strengthen them, but it so happens that a great many of those ribs have separated themselves from the arches that they originally were in contact with, and have tumbled down, one of the ribs now remaining in this arch; viz. that on the up stream or west side, is so far separated from the arch, and is in imminent danger of falling, that to prevent mischief to any that may be under it when it happens to fall, it will be proper to take it down: I do not apprehend it to be any ways necessary to rebuild it, because I cannot suppose it has ever been of any real use.

In

In the middle of this arch the stone work is entirely perforated by an area of about four yards by six; and as the bridge has been so constructed at first, this area had once been covered by a draw-bridge by way of defence, being so placed that, if open, the passage over the bridge, as it now is, between the houses would have been stopped thereby. This area is now floored with timber covered with earth, and paved at the top like the rest of the bridge, so that when carriages go over this part of it, the vibration of the timber makes it appear to shake. The main timbers are pretty strong, but the whole has been very roughly executed, and has all the appearance of a job done in a great hurry. It seems also to have had some repairs occasioned by the rotting of the ends of the great beams which have been supported by piers put under them; some of the small wood that is supported by the greater appears to be decayed; but while so supported nothing of great consequence can happen. In fact, I find the state of this flooring sensibly different from what it was when I viewed it in the year 1765, for that reason it may be supposed possible to continue for a number of years to come; but as it is a piece of work so put together, that one cannot answer for it, a failure may happen when it is least expected; and as the lives of men depend upon it, and it is in a visible state of decay, it appears to me that it ought to be repaired; and as it is very probable it may never be wanted again to serve the original intention, while it is doing I would recommend this area to be arched with stone, and as the centre may be erected underneath, and every thing prepared for turning the arch before any thing is disturbed upon the top, I apprehend all may be with ease completed in three days stoppage.

The next arch has lost all its ribs, yet shows no signs of infirmity, except that as the pen stones are in a double layer, composing an interior and an exterior arch, the former is a little separated from the latter, on the down stream side of the south haunch. Some repairs are wanted in the setting of the jetees of this arch, as also more or less in all the rest.

The fourth arch from the south side, or second from the draw-bridge arch, is called Keelman's arch: it has originally had five ribs underneath it, of which there is only one remaining; but it shews no loss by the want of them, the up stream shoulder of the pier on the south side of this arch, wants repairs; and together with the rest a number of small articles which it would be useless as well as tedious to mention.

As the whole of the repair is a kind of jobbing work, there is no ground upon which to form an estimate of the expense; for when part of an old edifice is pulled down in order to be repaired, it often discovers something unforeseen, of which a repair is equally necessary.

cessary; for this reason (except the arching of the draw-bridge area) it cannot well be done by contract, because a contractor will not do more than originally appeared, and thereby the fore may be left unbottomed; and if done by day-work, the expense will depend greatly upon the honesty and address of the workmen. But I should imagine the whole, stone-arching in the draw-bridge included, may be done as well as the state of the bridge will admit of, for 150l., or at most, 200l.

J. SMEATON.

*Ausborpe,
October 18th 1769.*

N.B. This part of the bridge belongs to the see of Durham. It fell down in a great flood in 17 ; and was rebuilt in its present form by Mr. Mylne.

REPORT of JOHN SMEATON, Engineer, upon the State of that Part of Tyne Bridge, belonging to the Town of Newcastle.

HAVING carefully viewed the north part of Tyne Bridge, the 30th of April 1771, being attended by Mr. Craister and Mr. Gunn, I am of opinion as follows.

That the whole of this bridge is founded upon piles fawn off above low water mark, in the manner of London Bridge, and in the same manner, each congeries of piles for supporting the pillars, is surrounded with a work of defence called sterlings or jetees, which, reaching from two to three feet above water, each probably one or two feet above the heads of the bearing piles, thereby defend them from decay, and from being fapped at the bottom by the immediate action of the water upon them. Those jetees, however, being chiefly constructed of timber, and being immediately exposed to the action of the water, are always in a perishing state, and therefore themselves gradually come under a course of repair, though they seem pretty effectually to have defended the bearing piles for supporting the superstructure, as there does not appear to me to be any shrink of the foundations which at present can be noticed. The jetees from the middle pier, that divides the counties, to the north shore, appear to be at present in tolerable order; some few stones are wanting from the upper surface, but which will be easily replaced in course of a repair.

The whole of the superstructure has more sensibly felt the effects of time, having been originally very ill built, and in general of too small stones, and not of the best kind; this

added to the great wear and tear occasioned by the frequent running of the keels against the piers and hips of the arches, has produced derangements that can never be effectually mended, because the new work, which from its nature must be superficial, can never be firmly united to the old, and therefore, those repairs cannot be of long duration, as they are easily displaced by fresh strokes, being chiefly retained by cramps of iron: from these causes almost the whole of the assler facing of the piers is loosened from the core of rubble work within, and which appears also to have been the case for a course of years back; the arches resting upon stones which are very much decayed, and which cannot be replaced without danger of bringing down the arches they support; this renders the whole superstructure in so ill circumstanced a situation that nothing lasting can be done at it.

It is not easy to fix the duration of a piece of stone work, as we daily see instances of old buildings hanging together in a surprising manner: and as the infirmities that I have pointed out are not of very recent date, nor any thing happened that is particularly alarming, I should expect that with constant attention to repair its defects as they gradually arise, this bridge may be supported many years longer; however, as it is not possible to be assured how long it may last, its apparent condition is such as would readily induce me to recommend the thoughts of a new one, if I could see a possibility of advising any thing to which there are not very manifest objections.

The most desirable situation seems to be a bridge below the present one, as being most central to the town; but the depth of water there is so great as to make such an undertaking exceedingly expensive.

The most easy, least expensive, and what could be done in far the shortest time, would be to build a new superstructure upon the old foundation; but as upon this plan it could not well be made above four feet wider than the present breadth where widest, and as there would be a necessity of continuing the present jetees, I apprehend this measure would stand universally condemned.

To put down new piers in the present situation, upon new foundations, so as to afterwards take away the jetees, would greatly prolong the time, and add to the expense and difficulty; especially as the places of the new piers would be obliged to conform to the old ones, and thereby increase the number of piers that would be necessary or eligible in an entire new structure.

To build a bridge above the present one, would be done at less expence than in any case, if an entire new one, but would be less central than the present.

I have endeavoured to throw together these general thoughts, that it may be clearly seen how the matter hinges. With respect to the current repairs that are now necessary, and of which it is not possible to make an estimate, being such as have usually happened; it is, however, necessary to say something respecting the rebuilding the land-breast and first arch from the north side.

The north arch is certainly in the most ragged condition of any; but being a small arch is in less danger of falling. The immediate rebuilding thereof depends upon another matter. If a building is to be erected upon the key-wall, connected with the land-breast, the land-breast wall is so bad above low water, as not to be safe to make any building intended to be durable upon it. The key-wall cannot properly be rebuilt, without doing that part also whereon the last arch of the bridge rests, being connected together. That part upon which the arch rests, cannot be done without taking down the arch, and when down it will not be proper to rebuild the arch without new doing the face of the pier, whereon its other haunch is to rest. The neglect of which, in rebuilding two or three other arches contiguous, which appear to have been done not very many years ago, will occasion their not being of longer duration than the old ones. In fine, if there is no immediate necessity of building upon the key-wall, and if there was any prospect of a new bridge, then the rebuilding of the said arch may be deferred; but if the bridge is to be supported as long as it can be, then I advise at all adventures to build up the wall and arch in the most effectual manner.

The great arch, which is next the division of the counties, and the sixth from the north shore, as also the arch next it north, commonly called the white arch, or fifth, appears to have been original. Those arches are built with ribs, which are now so much settled as to bear very little weight: two out of five in the great arch, and three out of five in the white arch are tumbled down, or have been driven down by the keels running against them; at present the north end of the lower rib of the white arch has by a stroke from a keel been driven sideways several inches out of its place; it is possible it may so hang for years; but as it is plain from this that it supports nothing, and as another stroke in the same way by another keel will infallibly bring it down, and by the fall thereof lives may be lost, it seems therefore adviseable to take it down.

J. SMEATON.

P. S. When

P. S. When the north arch is built, it seems practicable to make a foot passage on to the quay, which, as it will greatly ease the present narrow avenue to the bridge, will deserve consideration *.

MINUTES of a View of Newcastle Bridge, 30th April 1771, by JOHN SMEATON, Engineer.

Great Arch or 6th.

The great arch, being the sixth from the north side, beginning at the middle of the pier on the south springer of the said arch where the counties divide.

The down stream angle of the said pier between the town and the Bishop of Durham is in bad repair, and the face of the aisler wants new pointing, and filling up to high water mark, which is in general the case with the whole bridge.

When any of the salient angles are new done, I would advise their being rounded by a sweep of about 18 inches radius, by which means they will be less liable to be broken and dislocated by the keels, and that all the mortar used within the tides mark be made with pozzolana rather than terras.

The great arch has been originally built with five ribs, of which the two outside ones are gone, the penstones making the cover being put on joint and joint.

In the down stream course of penstones, a bad stone near the south springer ought to be in part screeded off, and supported by a fresh ingrafted stone. Near the north springer of the great arch both on the up stream and down stream sides, the joints in the penstones are become open; those most perished to be wedged and pointed.

Pier North of the Great Arch, or 5th from the North Shore.

Several cramps are loose, and stones out of the face, which should be repaired and pointed as before mentioned; in the jetee north side of the pier, some stones are out and want repair.

* Nothing was done, the bridge tumbled down in the greater part, and this portion thereof belonging to Newcastle, was rebuilt by Mr. Wooler, military engineer.

VOL. III.

L I

White

White Arch, or 5th.

This arch was also originally built with five ribs, of which one up stream and two down stream are gone, the penstones near the fourth springer on the down stream side are sharped off, and should be fresh abutted. The north springer of the down stream rib appears from the blow of a keel to have been driven several inches sideways out of its place, and as from hence it appears to support nothing, and may be driven down and do damage by such another accident, it seems best to take it down, nor can any new rib be erected, so as to answer any good end. The joints of the penstones towards the north springer are perished and want wedging.

Pier North of the White Arch, or 4th.

The outside stones in a general state of decay, and no particular failure; like the rest it wants new pointing.

The Tower Arch, or 4th.

This arch seems to have been new done since the original, but appears to be the first of those that have been rebuilt; it is without ribs, and not very substantial.

The penstones at the fourth springer on the up stream side are broken, but may be easily repaired. The penstones at the north springer both up and down stream are a good deal galled by the keels.

The Tower Pier, or 3rd.

The aisler on both sides that support the arches are a good deal wasted; the down stream point of the jetee has been damaged and wants repair.

The Arch North of the Tower Pier, or 3rd Arch.

This arch has been rebuilt without ribs in man's memory, is in tolerable good order, but is sprung from bad bearings.

The Pillar North of the Tower Pier, or 2nd Pillar.

The up stream point wants repair, and several stones are out of the faces, which need replacing.

The first Pillar from the North Shore.

This pillar seems in general in as good order as any, but its aislering depends altogether on cramps, and being out of the common road of the keels is not so apt to suffer thereby.

The

The first Arch next the North Shore.

This arch is at present in a very shattered condition, though part of it seems to have been rebuilt within the compass of a few years, the oldest part of it does not appear to have been original, but when rebuilt has been hastily done with bad workmanship and materials; the new part which is on the up stream side, has been very ill abutted, for it rests upon a base of about 18 inches broad at the north abutment, and is gained on upon the old work till it comes to the breadth of five or six feet.

The abutment of the north arch is upon a part of a quay wall, extending both above and below the bridge, the whole of which above low water is in a shattered condition, and seems very improper to build upon without first rebuilding the wall itself, at the same time taking down the north arch, and rebuilding both at the same time.

When this is done, I advise to clear away the north face of the first pier, to at least four feet in breadth, quite down to the foundation pile heads or platform; and if any thing there appears deficient to make it good with new, then to raise up this face of the pier with large and good aisler, in order to rest the south end of the arch thereon, by this means this will become a part of a new superstructure, and the rest being gradually served in the same way, will in time produce in effect a new erection.

It seems practicable to increase the breadth of the bridge so as to make it about four feet wider than at present, that is, about 20 feet wide within the parapets; 16 feet may be allowed for the carriage-way, which will admit two carriages to pass freely, and leave four feet for a raised walking path.

It is also practicable to make a foot-passage from the bridge through the old building to the quay, and from thence immediately to the sand hill, which will greatly relieve the present narrow avenue to that end of the bridge.

N.B. The jetees being chiefly timber, are in a general state of decay, but seem at present in tolerable order; what is most amiss has been particularly pointed out.

J. SMEATON.

Newcastle,
9th May, 1771.

A REPORT relative to Tyne Bridge.

THIS bridge having been erected some centuries ago, upon the principles that were then in common use for such edifices, as may be seen from many of the old bridges over great tide rivers in England, and also in several parts of Europe, namely upon stilts, surrounded with a kind of basement called starlings; has always had the same inconveniences and imperfections attending it, to which all others of this kind are subjected.

The stilts are a great number of large piles driven down into the bed of the river, supporting a timber platform or framing under each a little above the lowest water of the river, upon which the masonry is established, and these stilts being surrounded with a row of close piling at the distance of several feet, and the intervals filled up with gravel and other stone materials, thrown down at random; and the whole connected with proper timbers, and paved down at top with large stones, a few feet above low water mark, form the footing or basement for the security of the pier, which is called a starling.

Upon these principles this bridge has been hitherto supported, though the river is subject to rapid floods and drift ice in the season, without suffering any thing very considerable, except in one or two of its arches, within the memory of man.

The total breadth of the river between the quays or abutments being 539 feet, the piers or solids of the bridge took up or occupied a third part of it, and when the tide fell below the top of the starlings, they took up somewhat more than one half of the free water-way, immediately above bridge; and this great contraction of the water-way has at length contributed its effects towards bringing about its ruin, by increasing the rapidity of the stream passing under it, so much as to gull away the ground under the arches, sweep away some of the starlings, undermine the stilts, and throw down or render incapable of repairs, five of the arches out of ten whereof this bridge was formerly composed. The arches of the bridge itself are likewise too low, seven out of the ten being totally filled up with water above their crowns or key stones, by the late flood of the 17th of November last; which flood produced this, and many other unhappy events of the kind upon this and the neighbouring rivers.

This flood was three feet six inches higher at this bridge than the memory of man or tradition has ever taken notice of; and the ground on the east or lower side of the bridge is gulled away so as to produce a depth of twenty-seven feet six inches of water at low

water, when at a medium there is only seven and eight feet depth in the river immediately above the bridge, or on the west or upper side of it, and this circumstance is now mentioned to shew the danger the four remaining arches still continue exposed to, by standing as it were upon the edge of a precipice.

The inconvenience just now mentioned, arising from contraction of water-way by this manner of construction, and which at length has been fatal to the edifice itself, is far from being the only one which this mode of proceeding occasions; the trade now carried on upon this river, so necessary to the kingdom in general, requires many hundred of keels with coals, and other small vessels, to pass and repass under this bridge almost every tide, both in the day time and in the night. The starlings which project from six to eight feet from the piers, under each of the arches when covered a little by the tide, expose them unavoidably to frequent damages and losses, and often to utter ruin and destruction. And of such events, gentlemen conversant in the trade are sufficiently acquainted with numberless instances, so as to make it totally unnecessary to mention any further, than that the starlings themselves frequently suffer in the rencounter, and incessant blows contribute to their wanting frequent and expensive repairs.

Other inconveniences attending this bridge must now be mentioned, which are sufficiently known to every person who has had occasion to pass over it; one of which is the steep ascent from the south end of the bridge, rising one foot in seven or eight for a considerable space, with the confined narrow street all the way, which renders the whole extremely dangerous to every passenger, whether in a carriage, on horseback, or on foot, and frequently occasions great interruptions and confusion, when carriages or a number of passengers happen to meet upon it; and being the principal road of communication between Scotland and the southern parts of the kingdom, exposes every individual to those hazards, who has occasion to make use thereof. The other inconvenience is the narrowness of the bridge itself, which within the parapets is 15 feet wide only, and in several places reduced to 9 feet by buildings and other obstructions, and equally productive of the last mentioned hindrances, dangers and delays.

After this detail of circumstances relative to this bridge, the next consideration, of course, must be the manner of restoring it to public utility; and, in order to form a proper judgment hereupon, many trials, in order to ascertain the nature and quality of the ground close to the piers and starlings of the bridge, have been made by borings into the bed of the river, in most of which it was found clogged or filled up with loose stones or gravel, to the depth of 12, 15, or 17 feet below the bed, and afterwards a loose sand

with small gravel for 10, 12, or 15 feet more, and at a medium between 30 and 40 feet deep from the surface of low water before a solid bottom was met with, which on the south side of the river appeared to be a stiff clay, and on the north side a hard compact gravel.

Under these circumstances, the difficulty of restoring the part of this bridge which is fallen to the former state, *without the use of starlings*, will be sufficiently apparent to every person conversant in these matters; and though it may not be an impossibility in point of art to do it, supposing that time and expense were unlimited, yet it is one of those things that do not seem capable even of an estimate: and if starlings should be admitted, and the former method of construction allowed of, the difficulty of establishing them in a solid manner, as well as the foundations of two of the piers, which are totally overturned in such a heap of stones and rubbish, not only fallen down at present, but which appear from the borings to fill up the bed of the river to the depth above-mentioned, would be so great, and the execution so tedious, that it is difficult to form a judgment what the expense would amount to; and, after all, the bridge would be established with every inconvenience that now attends it, and which have already been enumerated, and at last remain equally exposed to the danger of being overturned by the next great flood, as well from the defects in the manner of establishing the foundations as the contracting of the water-way, and the want of a proper elevation of the arches.

In order to ascertain the nature of the ground under the bed of the river, two sets of borings have been made across it, the one about 50, and the other 100 yards above the present bridge, the latter from the place called the Javel Groop, to the opposite shore, from both of which a mass or body of loose sand mixed with small gravel from 12 to 30 feet in thickness or depth from the bed of the river, appears to cover a stiff clay, inclining from the said shore to near the middle of the river, and a mass of the same sand from 30 to 40 feet in depth, covers a hard compact gravel from the middle to the north shore, conformably to the borings made at the bridge itself, which have already been mentioned.

As the last mentioned place, or near it, seems to be the most convenient spot for erecting a new bridge whereby the inconvenience attending the old one might be removed, and, at the same time, preserve the best practicable communication from the town to the opposite shore, it necessarily remains to procure by art the means of establishing a solid foundation upon this great mass of sand and gravel; but as a detail of this part would run to too great a length, it may at present suffice just to mention the outlines of this proposition,

on, which are to span the river with seven arches only, whose piers or solids may not take up more than one-fifth part of the water-way, to lay the foundation of the piers and abutments several feet below the bed of the river upon a sufficient number of stout piles driven down under them, and to circumscribe each with a border of plank piling driven close to the foundations, and thus at once to remove the danger and inconvenience to the navigation arising from the starlings, and at the same time to admit of four-fifths of the breadth of the river to be free water-way: to give this new bridge more elevation than the old, to construct the piers and arches with large blocks of the hardest and most durable stones the country affords, to make the breadth of the bridge within the parapets 30 feet wide at least, with a paved way for foot passengers on each side, and to suffer no erections or buildings to ever occupy any part of that space, to keep its landing on the south shore as much elevated as possible, and to bring the road to join it 40 feet wide at least, from the top of the steep part of Battle Bank near the Half-moon Lane in a winding course round the hill, and by this means to reduce the descent or ascent to about 1 foot in 19 or 20, or thereabouts, which will not be very perceptible; to open the communication from the north end of the bridge to the *Glefe*, and after allowing a sufficient area or void space at each end of the bridge, its communication both ways will be rendered as convenient to passengers and carriages as it is capable of being made.

In order to communicate the road through Pipewell Gate, a dry arch can be made in the abutment; and to enable the inhabitants of that place, and the lower parts of Gateshead, to go over the bridge in the readiest way, a flight of stairs can be erected from Pipewell Gate to the top of the bridge in one or each side of the south abutment, if thought necessary.

It is, no doubt, an objection to the new placing of the bridge, that it will be detrimental to those who have houses in the thoroughfare down the Battle Bank, but when buildings happen to be erected in a place in such a manner as to be totally inconsistent with public accommodation, those partial inconveniences must either give way to the greater convenience of the public, or the public must submit to the having them entailed upon it to perpetuity: but to shew this in a clearer light, let us suppose a new bridge built in the old situation, whose superstructure is raised at the south end as much as the position of the present piers (which at all events it seems necessary to conform to), will admit of, then if a gradual slope be continued from the brow of the Battle Bank (where it begins to be steep, that is about 70 yards north of Half-moon Lane) to the bridge, it will form a slope of about 1 in 12½, which is not to be called an easy one; and in this case

case the surface of the road will be in some places near the bottom of the Battle Bank, 26 feet above the present pavement; so that the greatest part of all the houses down the Battle Bank must be rebuilt; nor can the road through Pipewell Gate be communicated with the bridge for horses or carriages without forming a slope almost 100 yards into Pipewell Gate, which will in like manner induce the necessity of rebuilding there, and the same of Hill Gate.

The slope may indeed be eased by beginning at Half-moon Lane, and cutting down the breast of the bank, but this will not bring the slope under $14\frac{1}{4}$ to 1; the height of the road above the present pavement will be nearly the same towards the bottom of the bank, and the set of houses where the ground will be cut, being undermined or left considerably above the pavement, will also need rebuilding to render them convenient, and after all, the narrowness of the street will be a permanent inconvenience, which cannot effectually be remedied without totally rebuilding the whole of it.

It seems, therefore, that there is no other choice on this matter, but either to rebuild the bridge upon its former principles, or to choose a new situation. It is not to be doubted but the bridge may be restored to what it was by proceeding upon the old plan, at less expense and in less time than the building of a new one; but the inconvenience of passage over and under before mentioned remaining with the public to perpetuity, can scarcely be counterbalanced by the saving of any moderate sum of money, nor can the public be well accommodated with a temporary bridge without being at a much greater charge.

It is not possible to judge completely of the expense of building a new bridge, till a just plan thereof is formed, and from thence an estimate made by a regular induction of particulars. But as this alone is in reality a work of time, to enable the gentlemen concerned to form their judgments of preliminary matters, we judge from the execution of similar works, that a bridge may be built at or near the Javel Groop to the opposite shore, including the extra expense on account of the whole bed of the river being a mass of sand, for the sum of 50,000l., from shore to shore, that is, exclusive of land-works and purchases. A bridge of this kind will probably take seven years to execute; and we are of opinion, that to build a new bridge in the old situation, and on the same principles as before, cannot be executed for less than half the money, and will take half the time,

From

From this proposition, the necessity of purchasing a considerable quantity of buildings and other private property for the use of the public, will be very apparent, in order to make the access to the bridge convenient on both sides of the river, and if all this were not wanted for the above mentioned purposes, a great deal would be absolutely necessary to be had for establishing yards and sheds for the workmen for performing the many different operations the edifice itself would require.

As the time necessary for completing this work will be so considerable; a better communication than the ferry already established, may probably be judged unavoidable during so long a space of time. In this case, a temporary bridge of timber materials, erected upon the stumps of the old piers, so as to join the four remaining arches with the abutment remaining on the south or gateshead shore, will be attended with the least expense and inconvenience of any other method, its whole length being only 320 feet, which is about $\frac{3}{4}$ parts breadth of the river. For effecting this, a proper design with a construction or detail of every particular, is now given in, and the expense computed at about 2400l.

Before this work can be performed, the single arch remaining towards the middle of the river must be taken down, and a little time will show whether this may be attempted with safety to the workmen, when it can be well ascertained, that the opening or rent therein has not increased any more for any considerable space of time. It is further recommended to take up the remains or ruins of the three arches and piers next gateshead shore, leaving the platforms or remains of the piers for establishing the legs of the temporary bridge upon; the performing this as speedily as possible, will procure more free water-way to the river, and in course some advantage as to the safety of the four remaining arches of the bridge, in case of another flood, by allowing the stream to pass more freely on the opposite shore. When the new bridge with its communications is completed, the temporary bridge, with the remains of the old bridge, may be taken away, and the river freed from its incumbrances to the navigation.

J. SMEATON.
J. WOOLER.

Austhorpe, January.

To Sir Walter Blackett Baronet, the Aldermen and Common Council
of Newcastle-upon-Tyne.

AN Estimate of the expense of erecting a temporary bridge with fir-timber upon the piers or legs of the old bridge at Newcastle upon Tyne, 9th December 1771.

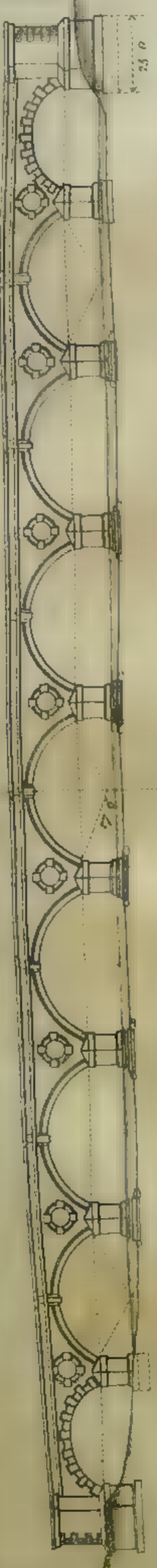
	£	s.	d.
14000 solid feet of fir-timber including the workmanship and scaffolding at 2s. per solid foot	1400	0	0
70 Cwt. of iron bolts and plates at 36s. per Cwt.	126	0	0
80 Do. of Do. and piles shoes at 28s. per Cwt.	112	0	0
Walling up the South Pier of the remaining from the Newcastle Shore, in order to support the end of the temporary the damaged sterlings, rooming up the work for security during the , and covering the top of the bridge with gravel, computed	770	0	0
	<u>£2408</u>	<u>0</u>	<u>0</u>

Feet Inches

539 6 the length of the old bridge, from Quay to Quay.
330 0 the length of the temporary bridge.

N. B. Notwithstanding this Report, the bridge was rebuilt in its old situation.

ELEVATION Fig. 1st



Scale of Feet.

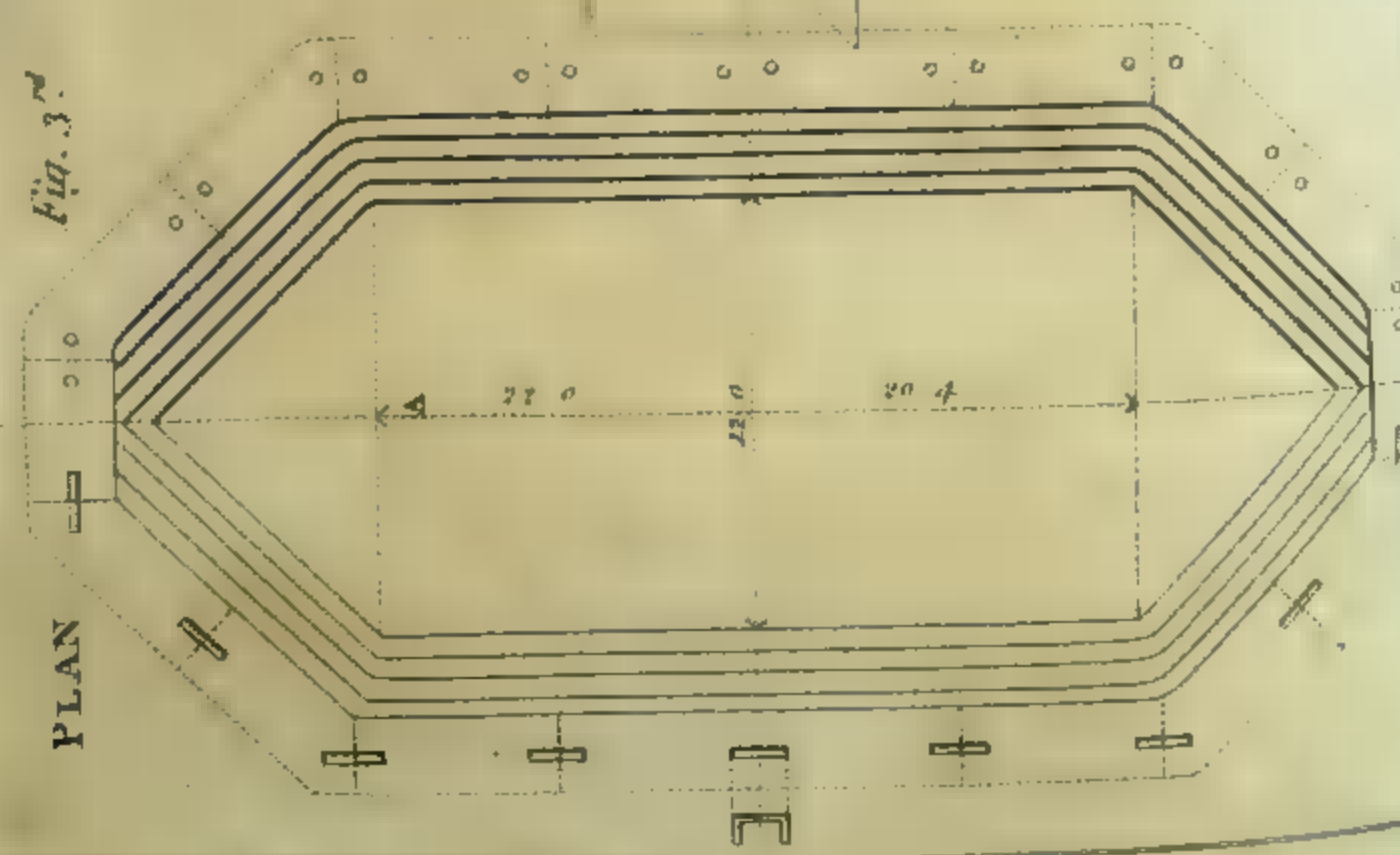
Design for a Bridge over the River Tyne near Hexham.

PLAN Fig. 2nd



Elevation of one of the Piers.

Fig. 3rd



Design for a Caisson for Laying-Down five of the Piers of Hexham Bridge.

Fig. 5th

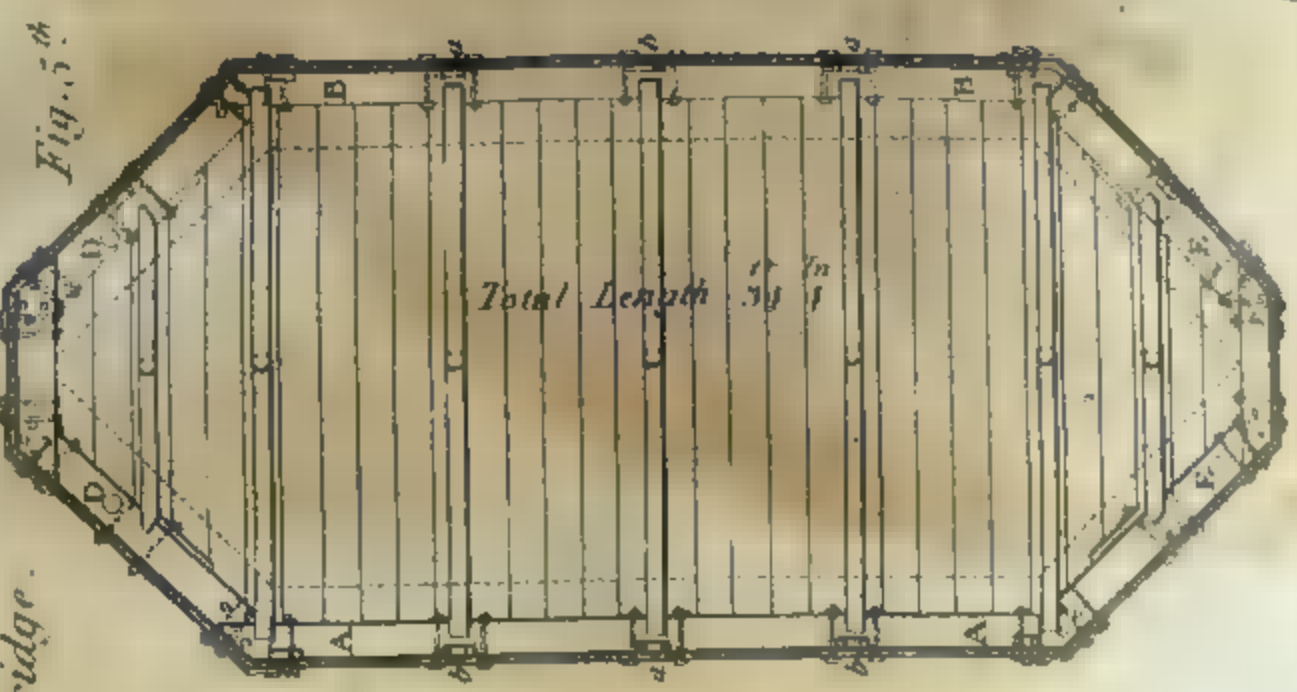


Fig. 6th

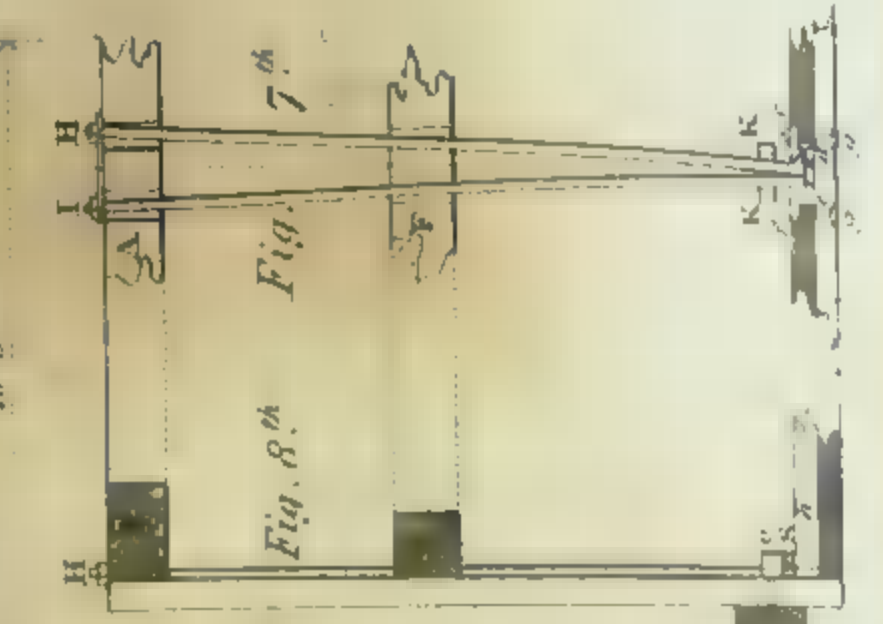
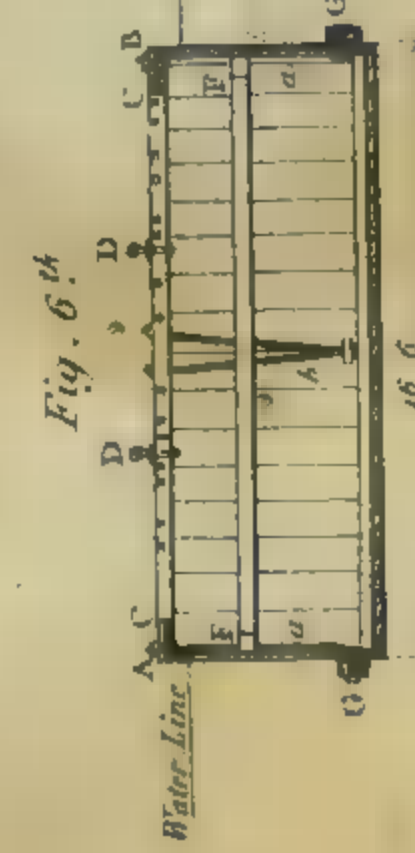
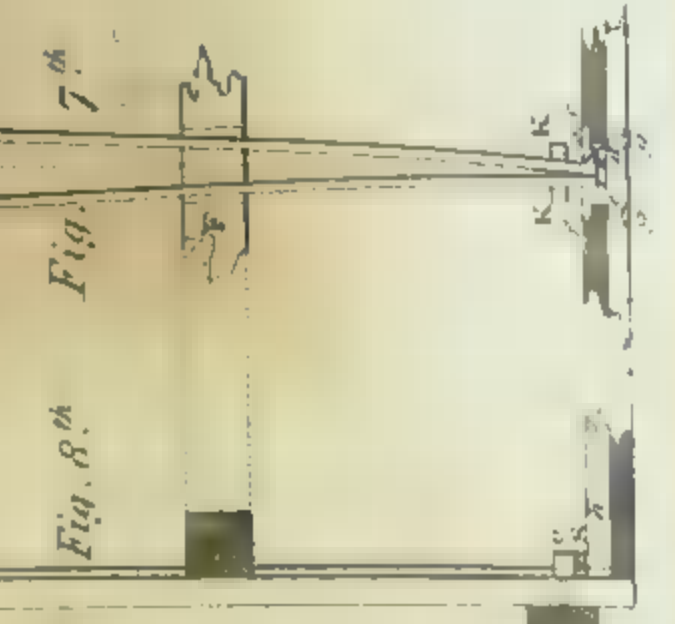


Fig. 7th



Scale to Figs 7, 8 & 9.

Scale to Figs 3, 4, 5 & 6.

HEXHAM BRIDGE.

(See Plates 11, 12, 13.)

To Mr. Donkin,
Sir

Aufthorpe, 12 January 1777.

I BEG leave to acquaint you, that I have fully considered the construction proper for a bridge over the river Tyne at Hexham. I have carefully computed every article of expense that will probably attend the execution of it in a substantial manner, and sufficient for me to risk my credit as an artist upon it. The situation is that which I particularly examined at the request of Mr. Errington, viz. about fifty yards below the boat, and nearly in a line with the little bridge that crosses the mill leet; in which case it will land at the north end upon the close east of the boat house, which is situate between that and the lane.

The bridge I propose to consist of nine arches, and to extend between the abutments 518 feet, and including the abutment well, 568 feet; to be twenty feet wide over all, and about eighteen feet between the parapets. I suppose it to be gravelled over in the manner of a good turnpike road, and the length of the road over the middle arch to be thirty-one feet above the surface of the river in its ordinary state: the height of the great inundation in the year 1771, being at this place above that surface scarcely fourteen feet.

The neat Estimate of materials and workmanship	£	s.	d.
Upon the above, I allow 10 per cent. for engines, utensils, and contingent expenses	6036	0	0
Expense of the bridge complete, with the road formed over it to the extent of the abutment walls	604	0	0
	£6640	0	0

To forming the ascents to the bridge at each end, that at the south to be wharfed up with walls extending fifty yards with a breast-work or rough parapet thereon, and so that the slope shall not be steeper than one in twelve; masonry, filling or forming the road to the extent of the slope

	£	s.	d.
	320	0	0
Total expense of the bridge complete, materials and workmanship	£6960	0	0

It is to be noted, that the road is supposed to be made up to the height of seven feet above the level of the ordinary surface of the river, and not higher.

It is further to be observed, that there is here no allowance for a small bridge over the mill leet; nor for forming the level road between that and the great bridge, nor for way leave or quarry leave, nor for the superintendence or surveyor's salary, which two last I cannot estimate at less than eight per cent. upon the above amounts, or at about 560l., making the whole sum 7520l.: so that, if Mr. Errington undertakes the bridge at a less sum than 7500l., with the intent of building it under my direction, it is probable he will be money out of pocket, and therefore lower than this I cannot advise his engaging therein.

I must observe, however, that the above is on supposition that every thing is to be provided, and therefore whatever the materials that are on hand may be found to be worth to this undertaking on a fair valuation, where they lie, will be so much to be deducted from the sum to be advanced by the country.

I cursorily viewed the situation opposite to the Hermitage, where I formerly proposed to build a bridge in 1756, and though I have no doubt of building a bridge there, yet to do it with a probability of safety against such a flood as that of 1771, which at that time was not thought of, is impossible there or in any other situation near Hexham, for less money than the amount of the above estimate.

I am, &c.

J. SMEATON.

To Mr. Pickernell.

London, August 8th 1777.

DIRECTIONS for forming the elliptical arches and centers for Hexham Bridge.

The true method of forming an ellipsis is by means of a trammel, with the construction of which I take it for granted you are well acquainted.

The dotted semi-ellipsis ABC (Plate 12, Fig 1.) is the medium line upon which the penstones are set out, by equal parts or divisions, and is 38 4 base, or width by 13 7 high, that is,

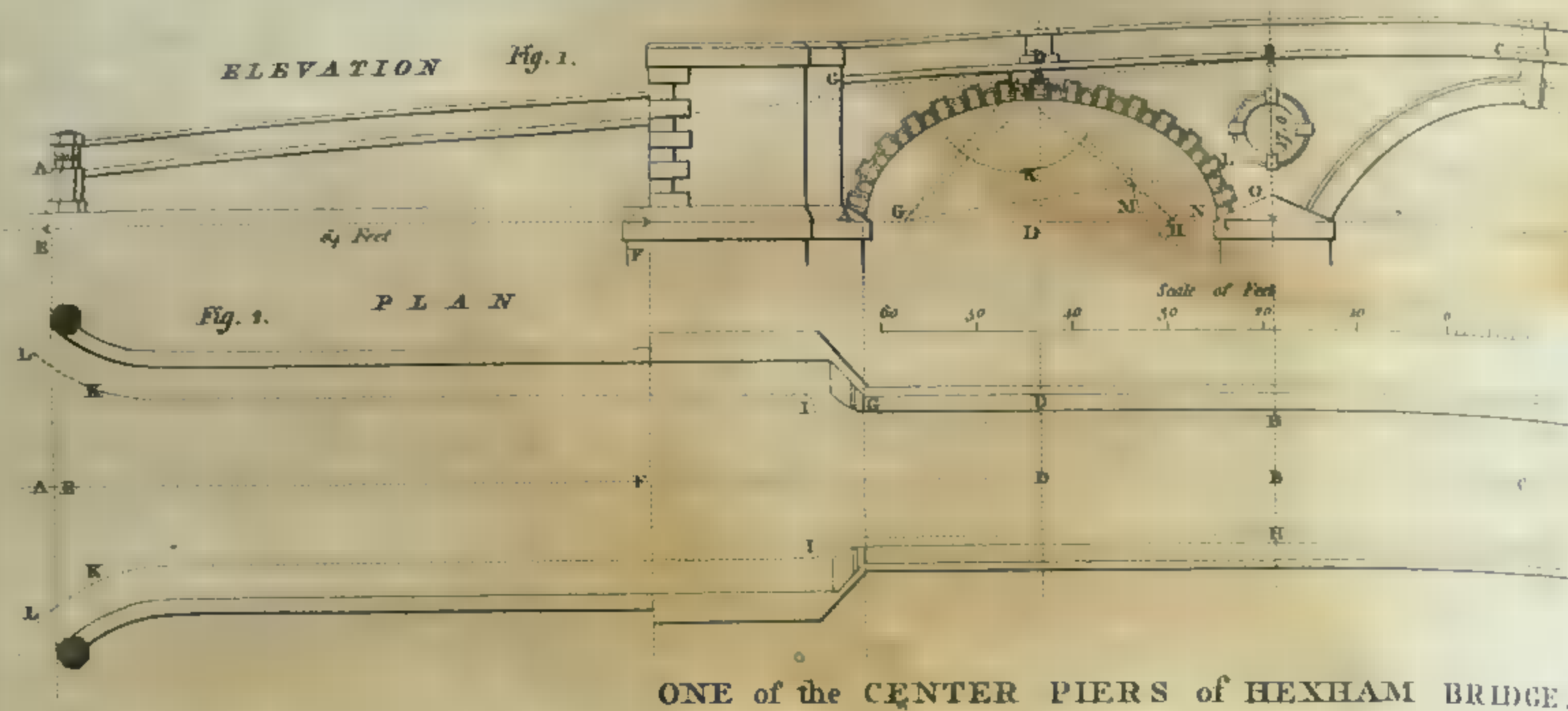
Ad—dC will be 19 2

dB . . . 13 7

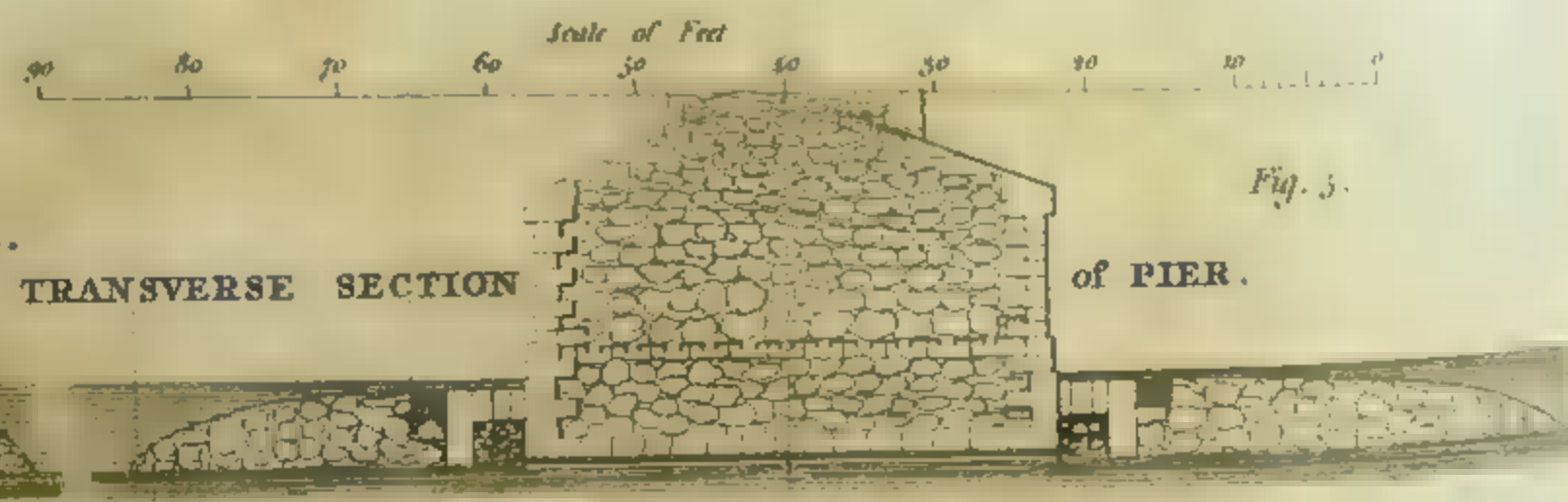
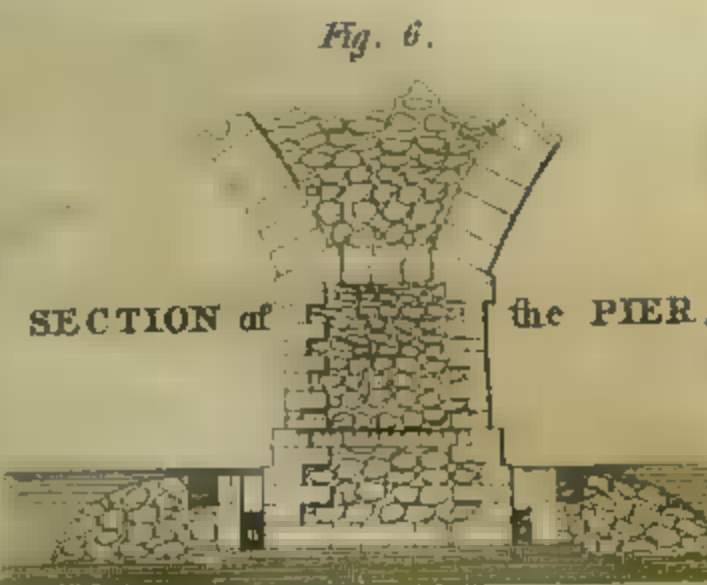
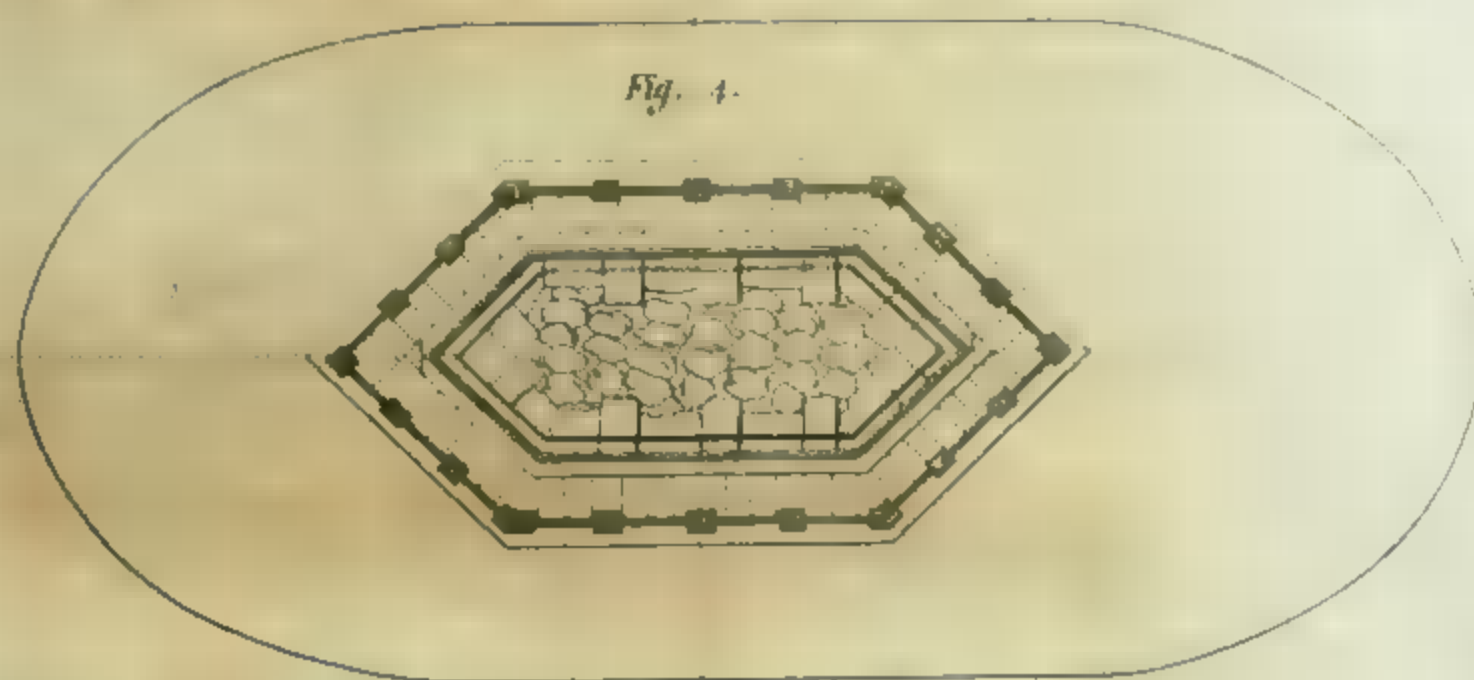
Difference 5 7

and

NORTH TERMINATION of HEXHAM BRIDGE.



TRANSVERSE SECTION of the NORTH TERMINATION.



TACKLE USED at PERTH BRIDGE.



and this difference of five feet seven inches will be the length of the cros grooves, from the center to the ends, say five feet eight inches, to keep the pins from slipping out; and five feet seven inches will also be the distance of the centers of the two pins that traverse in the grooves; laying down therefore your cros upon a floor, big enough to describe something more than half an arch, set your tracing point at the distance thirteen feet seven inches from the nearest traversing pin, and with this you will describe the curve EBF.L.C at large; and if your stones will run of twenty inches thickness, as drawn, set off ten inches BE—BF, on each side the center, and then divide the remainder FLC into 14 parts; but if your stones will only run about 18 inches, then set off nine inches on each side B, dividing the curve FLC into 16 parts; if your stones will hold but 15 inches, then set off 7½ or 8 inches for BE and BF, dividing the curve FLC into eighteen parts; and if they will not hold more than 14 inches, set off seven on each side, and divide into 20 parts. The points of division being thus fixed, shorten the distance between the tracing pin and the nearest traversing pin, to 12 feet 11 inches, and then you will describe the interior curve to be of 37 feet span, and 12 feet 11 inches high; and if from this you set out the tracing pin (pencil, or point) two feet, and three feet respectively, you will then describe the curves that will take the extremities of the short and long stones.

To find the directions of the joints, you take the line A d 19 feet 2 inches, and setting one point in B with the other describe an arch, so as to cut the line AC in G and in H, then will the two points G and H be the two foci of the ellipsis, which have this property; that if to any point of division of the curve as supposed L, you draw the lines GL and HL, then the line ML, bisecting the angle formed between the lines G and HL, will be the true direction or summering of the joint at L, and so of the rest. To avoid confusion, you have another example at the point I, the true summering of which joint is K I. In this manner the joints of one half of the arch with the key-stone, being neatly marked out upon the floor, and boards adapted thereto, (the grain of the wood corresponding with the length of the stone), you will have a set of molds by which all the stones in the two arches may be hewn; but you are to observe, the thickness of the penning within need not exceed the length of the shorter stones, the longer ones only appearing in front. You are also to observe, that the arch like a semicircle, begins from an horizontal line NO, representing the corner of the salient points of the pier rising up before the arch stone, or what may be better united therewith, by proper hewing, the ground joint being in the direction N C.

Respecting

Respecting the centers to the elliptical arches, the external curve will be struck out by the trammel, about two inches less than the soffit of the arch, to allow for the thickness of the boarding, and except the making of the curve quite fair, little curiosity otherwise will be required. I propose nine of these ribs, and the curved part may either be sawn out of crooked wood, or lapped together from straight, according to the convenience of your materials. The curves may be about seven by $3\frac{1}{2}$, and base 10 or 12 inches by $3\frac{1}{2}$ or 4 thick; the standards may be made out of any offal stuff you have, from $3\frac{1}{2}$ to 5 inches thick: in short the whole composition needs not to exceed that of vault centering, when well and firmly done. The base may stand on five bearings, one at each end, one in the middle, and one on each side the middle, but somewhat nearer the middle than the sides: perhaps it may be necessary to put in an upright more in the ribs on each side the middle one; for I would not have the spaces near the middle to exceed $2\frac{1}{2}$ or 3 feet distances at the top, middle and middle.

As the traversing ruler will be required 20 feet long, and to have a considerable degree of stiffness edgewise, to prevent its being over bulky or clumsy, it may be proper to observe that its greatest strength will be required at the middle pin, or the pin nearest the tracing point; you may therefore (making the whole $\frac{1}{4}$ thick) let the breadth at the middle pin be eight or nine inches; at the other traversing pint about four inches, and at the end of the tracing point about three inches.

J. SMEATON.

To Mr. Pickernell.

Inclosed you have the design for the caisson, for the five piers of the bridge that remain to be laid, as also the design and elevation for one of the center piers.

By "grooving in" of the sides, and cross course of bottom planks, as expressed in the explanation, I mean in the middle of the eye of each plank, like a common chamber floor grooved in with Dutch laths.

The reason why I would have the inside blocks joint more close in the first and second course than above is, that till the caisson is fairly grounded, we shall never be sure of keeping the joints whole; and as the second course will be sufficient to ground the pier, then all can be made good; and so long as the upper parts rest upon solid guaged blocks, and then upon one another, it is not absolutely material whether there were any fittings in the joints of these two bottom courses or not.

J. SMEATON.

EXPLANATION of the Design for a Caisson for laying down five Piers of Hexham Bridge.

Plate 11. Fig. 5. is the plan of the caisson, being 16 feet within, by 22 feet length of the flat side. The bottom is supposed to be made of three inch plank laid cross and cross; and the sides of three inch plank only, standing upright, and supported by three ribs of wood, two upon the inside and one upon the out. The uppermost AA, BB, to be strongly secured with bolts and plates at the angles, and likewise secured by bolts upon the sides, as shewn in the plan. The pieces CC, &c. are stretchers, but which being moveable, will not be in the way of lowering the stones. The sides not resting upon the bottom as has been usual, as to admit the stone-work to be flush with the bottom when the sides are removed, and thereby to let the girdle of large stones slip down to their own bearing, without being interrupted by any projection, a particular method of fastening the bottom and sides is adapted to this purpose, and the plates a, a, b, being 16 in number, each shewing a double nut and bolt, shew the places and disposition of those fastenings.

DD, EE, shew the places of iron studs, strongly screwed down, over which a chain being cast the caisson is thereby moored to a large pile, to be driven at the distance of 30 feet upstream of the bridge, before the point of each pier, to be kept steady by another small pile, about as much below.

Fig. 6. is a transverse section of the caisson, wherein is shewn that the ground tier of planks in the bottom run lengthways; AB shew the upper rib, the dotted lines CC shew the stretchers, DD the iron studs for mooring the caisson, FF the middle rib inside, and the dotted lines shew the moveable stretchers of six inches square, which, when the stone-work is got that height, are to be removed, and the sides supported by short studs against the masonry, if need be.

GG shew the section of the lower rib, which is put outside, to prevent its interference with the ground course of stone; this is four by eight; and as this and the middle ribs have no other use but to keep the upright planking steady they need only be spiked together; and on this account, if these ribs were of elm, or any other kind of wood than fir, they would be less apt to split by a multiplicity of spikes; a a shew two sets of the fastening bars seen sideways, and b shews a set seen in front; of which follows a more particular description.

Fig. 7. shews the upright of a pair of fastening bars to a larger scale, as they would appear from without if the outside planking was supposed to be removed or transparent; wherein A shews a part of the upper rib, F a part of the middle rib, and the dotted lines G shew the place of the bottom rib; c d e f shews a piece of cast iron let down flush into the edge of the bottom, and which is held down by the two bolts gg. This piece of cast iron contains a dove-tail notch, in which h H is the dove-tail bar; and thereby suspending the bottom upon the nut H; to which i I is the bar composing the key, which is to be driven in; but by turning the nut I will draw it out, and release the other, and by the same means all the fastenings in like manner being slackened, the sides of the caisson will be released from the bottom. KK is a staple whose use will be shewn hereafter. But as it will be necessary that the sides of the caisson should be under some confinement towards the bottom to preserve a water-tight joint between them,

Fig. 9. is a plan of a part of the bottom, wherein LL represent the side planking, GG the lower rib on the outside, and MM the cross planking of the bottom. Now m n o p is the plan of the cast-iron dove-tail notch piece; which notch being dove-tailed with respect to its plan, as seen here, as well as with respect to its upright, seen in fig. 7, and the bars being adapted thereto; by this means the bars will be confined from flying out sideways, as well as from drawing; and the staple ONN, shewn by dotted lines passing through the bottom rib, being tightened by the nuts NN, will draw and confine home the sides to the bottom; there is yet another thing wanting, and that is, that there being nothing to confine the sides from going below the bottom, there will be something necessary to counteract the nut H, fig. 7; now fig. 8, is an enlarged side view or section of the side of the caisson and bars, wherein the same letters denote the same things as the preceding, and the bar h H is supposed to be the same bar as marked with those letters fig. 7; now, if between the under side of the staple and the cast metal notch piece there be driven an iron key a little wedge-wise, whose section is represented by the little shaded part at S, the side can be so regulated as not to go below the bottom, and so to keep every thing sufficiently steady; nor is any degree of strength in this matter necessary, as the weight of stone in the caisson, when afloat, does not in reality hang by the fastenings, but is supported by the counter pressure of the water under it upwards.

As the bottom course of stone is to be close home to the sides of the caisson, grooves must be cut in the stones where they come against the fastenings, with full liberty to draw them out.

The notch pieces necessarily go along with the bottom, but one set of fastenings will do for all; and it will be proper to have the dovetail part of the bars well fitted to the notches with a file; care being taken to have the notches cast so near alike that fitting one they will fit all.

Though it is not mentioned in the description, it will be proper that all the joints of the planking and the sides, and the cross or upper planking of the bottom, be grooved in about three-fourths of an inch in depth; and a lath one and a half inch broad, and about three-fourths or one-half inch thick inserted, and let in with tar, that the pinning of the joints by drought may not induce the necessity of caulking; and to secure the joint between the bottom and sides it will be proper to nail on a stripe of thick flannel and tar three inches breadth upon the out edge of the upper tier of floor planking, and this joint may be further secured, if seen necessary, by a slight caulking inside.

Fig. 3. shews the plan, and fig. 4. the elevation of one of the middle piers, with the plan and section of the girdle of the stone round the base. The basement of the pier is supposed to consist of two courses of stone, both of which are to be made entirely of blocks; the interior blocks need not, however, be jointed as to their upright, or scrupulously fitted to each other, but to be brought to a thickness answerable to the course, and to be set upon their bigger bed as close to one another as may be, and the interstices carefully filled, and walled with best mortar.

The two upper courses reaching to the low-water level must also be interspersed with blocks gauged to a thickness, but need not be so close to each other as described for the two ground courses; if in these upper courses the gauged blocks occupy two-thirds of the solid within the outside course it will be sufficient. The first course of the base or chamfered plinth being above water is to have three chain courses go across it, that is three rows of blocks, one across the middle and one near each shoulder, to be strongly cramped together, and to the stones in the outside course, or joined by one continued bar across; and all the outside stones in the circumference of the chamfered course to be joined by one continued chain bar. In other respects, the masonry above the low-water line to be composed in the same way as the piers already executed above that line.

N. B. The shoulder angle of the girdle course, and of all the other courses under water is centered at A, in the plan, and the dotted line in the upright, denotes a slope of rock-work formed by a deposition of rubble, stone, and cement, called beton.

J. SMEATON.

Austhorpe,
17th Dec. 1777.

From Mr. Pickernell.

Hexham Bridge Office, July 2 1778.

I can now give you a particular account of the damage we have received from high water, which came on us last Tuesday night and Wednesday morning.

The pier which I last founded at the south side is undermined at the west point, and settled down considerably. I measured the water and found the gravel to be taken away about 18 inches below the bottom of the caisson. The foundation of the fourth pier from the south abutment is taken out at the south end, and nearly half along the pier, so as to let the west point, or cut-water, settle about 18 inches. The gravel is taken out in some parts, as nearly as I can find, two feet six inches lower than it was when the beton was laid on the bed of the river, and stones are taken out of the cut-water part of the pier. The water came with such force as to undermine the girdle-stones, and force up betwixt them and the pier so as to force the girdle-stones two feet from the pier. In some parts the iron cramps which were laid into the base courses have confined that part together, or else, I believe, all the cut-water part of the pier would have been entirely swept away by the violence of the stream. Though the water was not very high, I never saw it so strong.

I cannot see that the fourth pier from the north has received any damage, except that the bed of the river round the sinking stones at the west end of the pier is in part taken away; though, I believe, had it been as high as the other it must have suffered the same fate. The third foundation from the north abutment has suffered the same as the second from the south abutment. The gravel is taken out from under the west cut-water about 18 inches, and the point is settled down. Indeed I had not the good fortune to have the girdle course laid round the west part of the two foundations, as we could not get them at the quarry fast enough. None of the foundations which were laid last season have received any damage.

I am, &c.

J. PICKERNELL.

To Mr. Donkin.

Austhorpe, 29th July 1788.

I have received a particular account from Mr. Pickernell of our very disagreeable misfortune, and find it no ways more flattering than I had reason to expect from the contents of your letter. What I most blame myself for is, in not ordering every pier to be secured, not only with the girdle course complete, but with the slopes of rubble stones brought up against it, before another pier was laid on the bed of the river; because notwithstanding what has happened, had the foundations been secured, and finished in

in the manner I had intended and proposed, before winter, I am fully satisfied this disaster would not have happened. As it was, I was willing to push on the work in the prime of the season, and confiding in the natural strength and compactness of the gravel bottom, I could not have supposed so much derangement would have happened in the course of two or three summer freshes. I hope I shall not find matters irretrievable.

DIRECTIONS for securing and repairing the under-washed Piers at Hexham Bridge.

NOTWITHSTANDING the natural hardness of the upper crust of the gravel bottom, it being now found not capable of resisting the action of the water in sudden and rapid floods, it appears necessary to inclose the several foundations by a fence, or case of sheet piling, to prevent, at all extremities, the gravel from washing from under the bases of the piers; a plan for the doing whereof accompanies these directions.

The work may be begun upon any of the piers that are found convenient, and as soon as may be, the bays composing the two sheets that form the salient point before the west end of each pier ought to be completed, together with one bay of the return upon each side of the pier; and as soon as this is done the cavity washed below the bed of the river should be filled up rather higher than the original bed of the river both inside and out. The outside to be filled with rough rubble stones from the upper bed of Oakwood Bank quarry, which are exceedingly well adapted for this purpose, to be of promiscuous sizes, the largest not exceeding half a cube foot, or about 70lb. weight. The inside to be filled with the same kind of quarry rubble of promiscuous sizes, the largest not to exceed that of a large double fist, or about 12lb. weight, and for every two bushels or measures of rubble used within the case one bushel of clean sand must be thrown upon them.

This done, the desirable thing would be to proceed thus far with all the four piers that have been laid down in caissons, by which means all the piers will be guarded from further damage, after which the completion of the casing can be done more at leisure, nor ought this to be omitted with respect to the north pier of the center arch, which, though it has suffered no material derangement from the late floods, yet experience shewing that the gravel bottom ought not to be trusted, the same means should be applied as a guard to its safety as to the rest. However, if the piling is found to go on with

with readiness and facility, and the moving of the tackle from pier to pier a work of labour, then, at the discretion of the surveyor, the piers may in turn be furrounded wholly before the tackle is moved.

As soon as the gage piles are driven, the screw clamp may be applied upon the surface of the water; or indeed if the piling of each pier be gone on without removal, this clamp may originally be applied as an outward frame for directing the driving of the gage piles, and for retaining them in their places while the sheet piles are driven; and for greater facility, certainty, and exactness, in driving the sheet piling, so as to render them water-tight, I would recommend the long sides to be divided into four bays, and the salient point sides into three each.

When the case is completed, reaching above low-water, it may be tried whether the water can easily be got out, and if so, the under pinning, where wanted round the skirts of the caisson bottom, may be done by men's hands; but if not, the whole of the interstice between the case and the pier must be fitted with rubble and sand, as before directed for the west ends, about six or eight inches higher than the bottom of the caisson, and afterward driven down by a sett of about one foot square at the lower end, acted upon by one of the hand-rams: this will cause the matter to spread under the skirts of the caisson bottom, and the case hindering it from spreading outward will render all tight and firm. This done, the interspace between the case and the sides of the pier must be chocked in with blocks of the thickness proposed for the girdle or sunken course, which being scap-pelled to a tolerable square, and adapted to their places, they will not need cramping; but yet, to prevent any violent flood from turning any of them out of their places, it must be observed to chamfer the upper or leading edge of each cross joint, as shewn in a detached figure, as also to pin them fast with wedges, stones, and pebble mortar, or beton, which may be easily done if the case can be drained, as I expect it may, so as to dry the upper surface of the sunken course. This being done, the whole of the casing is to be driven down with setts, or otherwise cut off to the level of the sunken course, and the screw clamp ultimately fixed, so as to be rather below the tops of the piles, which will effectually confine all close home together.

The work being thus fixed, the outside of the case is to be guarded with a slope of rubble, which, that it may be the better grounded by a competent body of matter, it will be advisable first to let the work stand the effect of a flood; and then not only filling up the excavation that may be expected on the outside of the cases, up to the general level of the bed of the river, but forming a slope extending to the distance of about six feet upon the base, at the height of

of the bed of the river, and to reach as high as the clamp. After this, the slopes must be examined at every flood, and supplied where found deficient till the matter appears to be at rest, which sooner or later will be the case, when the river hath formed itself such a channel between the piers as is natural to the new sett of the stream, that the interposition of the piers of the bridge must necessarily occasion.

In case by repeated floods while the work is going on, any of the foundations shall appear to underwash more than they have done, it will be proper to throw round the west end and west shoulder of such pier a competent body of rubble, the largest not weighing more than 25 or 30 lb.; for through rubble of this size piles may afterwards be driven nearly as well as through large gravel.

The length of the piles should conform to the depth of the water. I would not wish the sheeting piles round the west end and first bay of the return on each side to go into the ground more than about ten feet; and if they do not drive kindly, must be contented with less; from thence each bay may be gradually less depth into the ground, so that round the down stream pointing seven feet will be sufficient.

If the gage piles drive more kindly, they may be longer by 18 inches or two feet than the sheeting; but if not, they need not be above one foot longer: and to make them drive kindly, as well as fix faster, it will be proper to point them longer than heretofore, that is, to about three feet, but not shouldering, as with a regular taper, but curved, beginning from nothing at three feet.

The length of the piles covering the west end and returns of the fifth pier from the north, being that most underwashed, the sheet piles should be at least 15 feet long, and the gage piles in proportion, and the rest proportionable to the depth of the water; and respecting this pier, as the lowering of the water in the case will be more necessary than in the rest, it will be proper before any rubble is put in outside the case, to put a layer of earth or loam upon the bottom, amounting to about six inches thickness, that is, allow a cube yard to six yards superficial, this will choke up the pores of the gravel in the deep places, and retard the percolation of the water through the gravel, so as to give a better chance of getting out the water, for new founding the west end, if deemed necessary.

What regards the repairs of the masonry I shall defer to a future opportunity of delivering, in due time.

It will be proper, in driving the gage piles, to try to use the great ram, fitted with a moveable discharger, so as not to be lifted above six or eight feet above the pile heads; by which means I apprehend it will be found to drive the piles much more kindly than if lifted its full height, and perhaps more kindly than the hand ram.

J. SMEATON.

Hexham,
5th August, 1778.

Additional Instructions.

When the caisson bottom is fully underpinned, according to the method described, let the point be taken down one course as far as the shoulder, substituting other stones of superior thickness, so as to raise the point rather higher than it was originally, by $1\frac{1}{2}$ or 2 inches; reconciling, however, the new with the old work at top, and cramping every stone to its neighbour, and to the block stones of the old work, with common mason cramps, run in with lead at each end, to bring them to a bearing, or otherwise fixing them fast with wedges. If you should have any difficulty to get them dry enough to run in the lead, heating the cramp, and putting a little oil into the holes, will render the difficulty less.

The taking up one course will do for the third and seventh piers; but for the fifth you may take down and cramp as before directed, as far as you can.

I have also considered, that if you can but get large stones for the up-stream pointings of the girdle course, or sunken course, the rest may be done with aisler, whose breadth and length is sufficient; and if you can get the water off, as I expect you will, so as to point and fill with the very best mortar, which when struck to a breadth will make the open joint upward, and more capable of being filled. I would not, however, have any thing pointed from the down stream shoulders to the down stream point; only chocked fast with stones or wedges, leaving interstices there for what water may get in at the up stream part of the pier, to make its escape freely below. Such of the old aislars as will answer to the length and breadth will effectually serve the purpose without any new dressing.

J. SMEATON.

9th August 1779.

EXPLANATION of the Designs for the Diving Machine for Hexham Bridge.

(See Plate 13.)

To Mr. Pickernell.

Sir,

Austhorpe, 16th September 1778.

IF the cases would have enabled us to reduce the water so low as to be even with the very bottoms of the caissons of each pier, I take for granted you would have thought it no difficulty with broken rubble, beton, stones, and short blocks of wood cut a little wedge-ways, to have crammed and wedged the cavity underwashed, under the wooden bottoms; so as to have been equally strong, and capable of bearing a weight with the original gravel, and particularly when this new body of matter is supported, and even jammed tighter into its place, by filling up the vacancy between the pier and the case, a little above the wooden bottom with rubble, and then driving it tight down by a sett with the ram. It therefore now remains, that I describe, and make you master of a piece of machinery, that will put you nearly into the same condition, as if the water could have been reduced to the caisson's bottoms as before mentioned; and this is by means of an air chest or diving vessel, which being let down will exclude the water down to the very bottom of the river, if you please; and therefore as low as the underside of the wooden bottom, which in the present case is as low as will be necessary or useful; and the chest or vessel being large enough to give liberty for a man to work therein; being furnished with a pair of boots, he will at mid-leg deep in water, do his business with almost as much facility as if the water were pumped out to the same level.

The principal part of this machine will consist of a strong chest, suppose three feet six inches in length, about four and a half feet depth or height, and as wide as to give free leave for its going down between the cases and the piers, which I suppose will be about two feet wide inside measure, as the other measures are also supposed to be. Now you know very well, that if you push a drinking glass, or any other similar vessel with its mouth downwards into the water; that it will exclude the water, leaving the vessel full of air, as it was before it was thrust into the water; in like manner, if this chest, being loaded with a sufficient weight, be let down into the water mouth downwards, the air will exclude the water to the bottom skirt of the chest, and if let down so as to rest upon the bottom of the river, a man may stand dry therein, and do any kind of business, the same as he could do in the same space in the open air. But to continue this for any length of time, two things are obviously necessary, and those are light, and a circulation of fresh air. The former might on occasion be supplied by a candle; but here we may have the advantage of

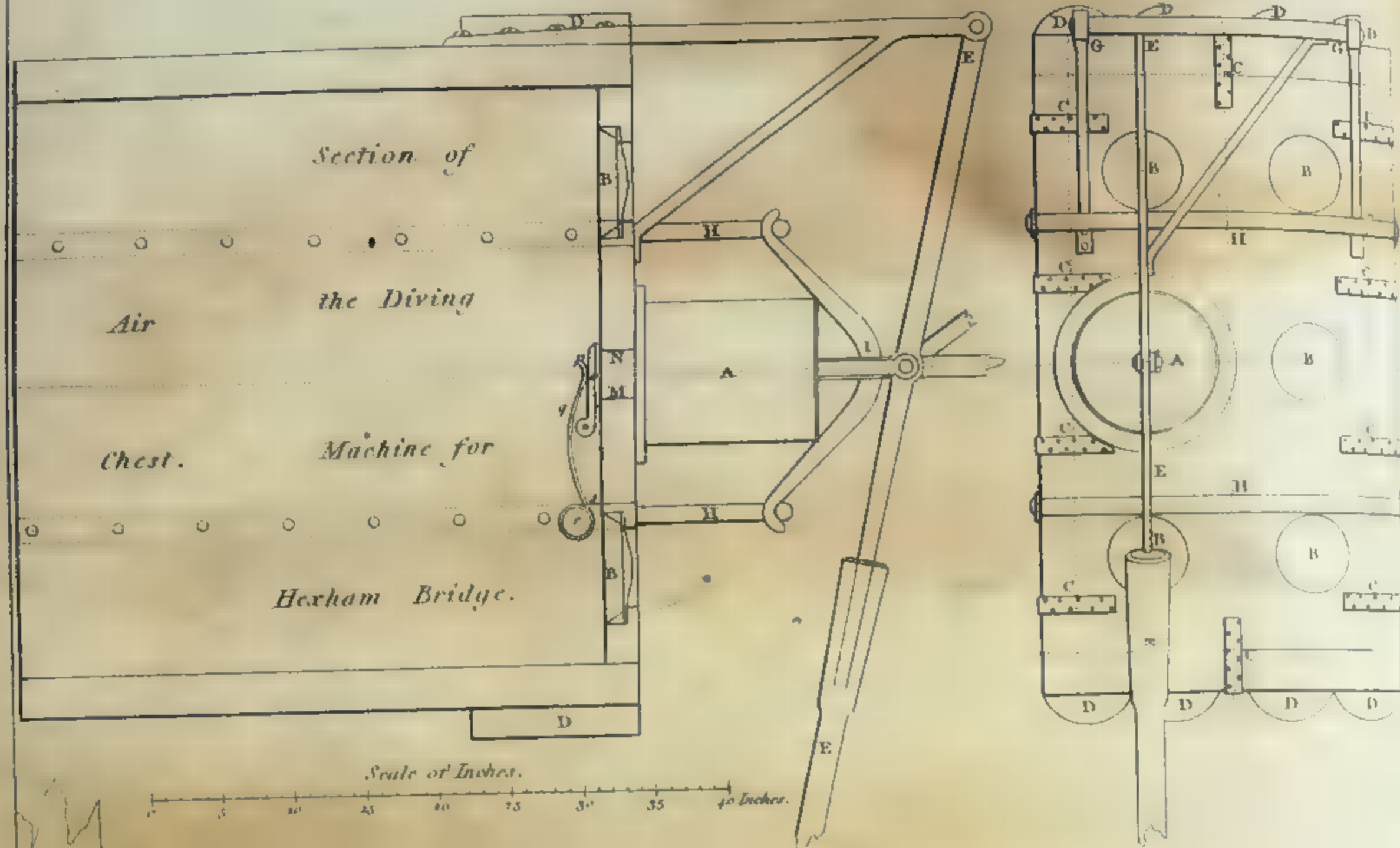
of day-light, by putting in two or three strong round panes of glass into the bottom of the chest, which will in its inverted situation in use be the top; a sufficiency of light will enter, this top of the chest being supposed above water.

Respecting air, you will conceive that any quantity might be forced in by a strong pair of bellows; but these made of leather, would be cumbersome and unhandy. I therefore substitute a kind of forcing air-pump, made of thin hammered copper, that will throw in a gallon at a stroke; which will not only continually refresh the workman within, but whatever air escapes out through the joints or pores of the air-chest, will be replenished, and the overplus go out at the bottom or skirt of the chest, and boil up on the outside.

The quantity of weight that will sink it mouth downwards, will be the same as placed therein (bottom downward) would sink it the same depth, and as this chest I propose to be suspended by a tackle, and to go down by its own weight, I compute that it will take 16 pigs of lead to sink it to the bottom of the river, and keep it steady; I propose that the lead may be as much out of the way as possible, to place them upon the ends of the chest, endways upward, that is, four in a row below, and four above, and the same at the other end; making in the whole 16 pigs, which are to be fastened on with screws, either by cleats screwed on, or punching a hole through each end of each pig.

At one end of the chest there is to be a board fixed across for the man to sit upon, and a cleat nailed on each side, to set each of his feet upon, so that while the machine is letting down or hoisting, he is totally dry, and when let down low enough, he stands upon the bottom of the river, without any more water than the height between the skirt of the chest, and the bottom of the river, which may be more or less as is found convenient, I suppose never more than a foot deep; because wherever the ground is taken out more than one foot below the under-side of the caisson's bottom, I would propose to fill it up with rubble previously to that height or depth; nor can it be of use to let down the skirt of the chest much below the caisson bottom, because the side of the chest will then diminish the room you will have, to get the matter for underpinning under the caisson bottom.

The foregoing will I believe be sufficient for explaining the general principles and outlines of the method I mean to pursue in underpinning, and re-supplying what is underwashed from the bases of the piers, and which I dare say you will now see to be entirely practicable.



What you are therefore immediately to put in hand, is the air-chest, of or about the inside dimensions before mentioned; I believe the two flat sides will do very well, if of good red wood deal shot clean of sap, the two ends and bottom (or in use its top), it would be well if they could be got of single planks of elm, beach, or plain tree, as they would hold the nails better; I fancy $1\frac{1}{2}$, or $1\frac{3}{4}$ thick for the sides, and $2\frac{1}{4}$ or $2\frac{3}{4}$ for the ends and bottom, will be sufficient; they should be well jointed, and put together with white lead and oil, and the inside joints stroked with white lead and oil, as the effort will not be of the water to enter, but of the air to escape from within.

Were I with you when it is put in use, I should be the first to go down in it, as there is no more danger (all your tackle being firmly fixed,) than being let down into a coal pit by a rope; and if it shall happen that all your masons are too fine fingered, I fancy a couple of colliers to take turn and turn, will find it a very comfortable job; a particular encouragement must however I expect be given.

I will give you more particular directions in my next: as to the air-pump, all that will be wanted from the copper-smith will be a cylindrical pipe of copper, 10 inches diameter and 12 inches high, wired at top, and a flanch at bottom of about $1\frac{1}{2}$ inch broad, by which it is screwed down upon the top of the air-chest; the copper to be about the thickness of a halfpenny; if you have no neat handed copper-smith, that can hammer it straight and smooth inside, it may on occasion be made of strong tin.

I am, Sir, your most humble servant,
J. SMEATON.

The materials will be got into the chest by letting them down in a shallow bucket or box, that will go under the skirt of the air-chest; which should be let down upon blocks to keep it steady, while the air pump is worked; you will do well to try it, first in shallow water, and deeper by degrees, from whence you will find the nature of its working.

Explanation of the Section of the Air Pump, Plate 13.

A—The piston shank and flanch terminating in

B—A screw by which the whole is compressed together.

C—Leather to keep the joint air tight.

Vol. III.

O o

D—The

D—The upper plate (to be made of boiler plate), $\frac{1}{8}$ inch less in diameter than the copper barrel.

E—A flat middling piece of shoe upper leather, turned down upon the border to make a tight joint with the barrel, and which also composes the valves.

F—The under plate (also of boiler plate), the edge being a little raised round the border, and about $\frac{1}{8}$ less than the barrel: the leather D being held tight between these two plates.

G—A piece of wood by way of butt or stop upon

HI—The upper surface of the plank of the chest's bottom, in its inverted situation.

K—An iron ring, and

L—The nut that fixes all fast.

MN—The opening through the plank, by which the air passes into the chest, and is shut by a valve or clack on the under side.

OP—Shews the opening through the upper plate.

QR—Ditto through the lower plate.

S—The solid part of the leather that shuts the hole OP when the piston is forced down, and gives leave, by means of its four arms, for the air to enter when it is drawn up.

Explanation of the Plan of the Air Pump.

FF—Shews the under plate, and under face of the piston.

EE—The leather.

qr—The holes through the same.

op—The holes through the upper plate, as they would appear if the leather were removed.

At *st*, *st*, the leather appears in place; and *vw*, *vw*, those spaces being cut away, give leave for the air to pass in going downward from above, while the piston is ascending; but not to escape from below upward, while the piston is forced down.

N. B. the rest of the letters marked upon the plan refer to the same things as the same letters refer to in the section.

XX—Shew the square heads of small screws tapped into the opposite plate, in order to hold the plates close together near the border, as the nutt and screw do in the middle: the heads, however, will be better above.

Explanation of the Plan of the Air Chest.

A—The air-pump.

B—The sky lights 6 inches diameter each, to be made of window glass knobbs, if plate glass is not to be had.

C—Clamp plates of iron to confine the top and sides strongly together.

DD—Pigs of lead, end upward.

EE—The lever for working the pump.

GG—The axis and brace for steadying the lever.

HH—Two bows for hoisting the chest.

Explanation of the Section of the Air Chest.

The same letters referring to the same things as in the plan.

I—A strong crooked iron to lay hold of the bows to which the main rope or tackle is to be fixed.

MN—The opening from the pump to the air chest.

op—The valve; whereof *o* is leather, *p* wood; to be shut by a wire spring, *qrs*, a little more than sufficient to overcome the weight of the valve.

To Mr. Pickernell.

Sir,

London, 1st April, 1779.

As I look upon it that the judiciously setting on of the base courses upon the damaged foundations is a very material point of consideration, it was for this reason that I was willing to take the whole of the winter fully to make up my mind about it; and having now seen the first of April, I shall no longer defer setting you at liberty.

You will readily comprehend, that if, instead of beginning with masonry from the bottom, two or three large detached pieces of rocks had been deposited in the river, of a sufficient size to build our piers upon; these serving as feet to stand upon, and each capable of supporting a proportion of the weight: those rocks, though unconnected below, yet if they are firmly connected at the surface of the water, by a cap of stone well cramped and united in one; this cap would serve as a new basement that could not separate, whereon to raise the rest of the superstructure.

Our piers in some degree answer the above idea; and it will now be our business to make a cap of the two basement courses, bonded together with a degree of firmness that would not have been necessary, had no derangement ever happened.

I propose, therefore, that the two basement courses be filled in with block stones, gauged to a proper thickness in respect to their beds; and so far struck off upon their sides, as to give opportunity to cramp them to one another, both inside and out. The outside stones I would advise to be cramped to one another with cramps from $1\frac{1}{4}$ to 2 inches broad, and from $\frac{3}{4}$ to $\frac{1}{2}$ thick, all well leaded in, and of sufficient length to get at least six inches fair hold of each stone. The whole to be bedded and worked in with terras mortar, of which I will give you the composition.

In the next place, as the ground could not be consolidated with piles under the first foundations, I always expected these to settle to the value of an inch more than the piers that have piles underneath them; but as in consequence of our derangements, our bearings will be rendered in some degree unequal, a greater settlement may be expected to take place at the west, than at the east end; for these reasons I would have the basement courses so suited to the present work, that the east end of the basement shall finish an inch higher than the finished piers; and the west end two inches higher; also that the west point and shoulders be carried $1\frac{1}{2}$ inch further west than the finished piers, so as to make the piers $1\frac{1}{2}$ inch longer than the former. In raising the shafts, I would gradually lose this $1\frac{1}{2}$ inch in getting up to the impost, by setting on about the value of $\frac{1}{4}$ of an inch at each course;

course; so that the impost will be of the same length as the former, but still finished one inch higher at the east, and two inches higher at the west ends. Now if afterwards the weight of the arches and superincumbent matter should not press down the piers in the proportion allowed for, this will make no apparent fault; because it will rather give addition of elevation to the middle of the bridge; and if the settlement should be double to what is allowed for, which I think is as much as can possibly be expected, it will still be scarcely visible. The main thing, therefore, that we have to guard against in carrying up our piers, is to do them with that care and solidity, that though the bearings may be somewhat unequal, yet that the whole may go together, without shewing any setts or rends in the outside aisler; and which, though it may happen without any material detriment to the real solidity and duration of the work, yet will disgrace our building in the eyes of those very many (in proportion to the whole) who can neither see nor reason any further; on which account I would constantly keep the west end some courses higher than the rest, building up as it were a head, and making off the courses. I would also cramp every course in the outside aisler, from the west point to half-way down the long sides, and every other course down to the east shoulders, till you come to the next course below the impost; at which height I would throw three block or chain courses across, in the manner I formerly ordered; there let the work of each pier stand as long as we can, and afterwards finish as has been already done. I mean what relates to the cramping above the basement to regard chiefly the third and seventh piers: as to the fourth, after the cap is on, as before, I think it will be sufficient to cramp every other course from the point to half-way down the sides only; but in regard to the cross chain courses at the height above mentioned, no caisson pier should want them. In regard to the fifth, I must suspend all directions till I see how it is likely to turn out.

The place where I am most apprehensive that setts may appear, is about a yard below or down stream of the west shoulders. I would therefore have you avoid putting in long stones faceways, near those parts; for though this may cause a few more cramps, and in common apprehension not be so strong: yet, as every joint will give way a little, it will prevent the breaking of the stones in the middle, nor will the weight above act by such long levers to break them.

Instead of our former terras mortar, take as follows:

Common lime 1, barrow lime 1, terras $\frac{1}{2}$, sand $1\frac{1}{2}$; — this dose with pebbles what you can, for rough work.

To

To set stones under water :

Barrow lime 1, terras 1, very small pebbles 1 ;— this being very well beaten, and let grow rather stiff, put it down in lumps about the size of a pullett's egg. If you have an opportunity of flat bearings, you may mortar the under side of the stone to be let down.

Below you have my description and directions concerning the new tackles.

I am, &c.

J. SMEATON.

DESCRIPTION of the Shears and Tackle that were made Use of in raising the Piers, &c. of the Bridge of Perth, and recommended for Use in Hexham Bridge.

(See plate 12. fig. 7.)

AB shews one of the shear logs, which are framed into a foal piece being of nearly the same height and scantling as the shears, that is, about six inches, but instead of being fixed by back stays, they are made to overfet by guide ropes commanded by tackle blocks in the following manner :

The guide rope CD is supposed to be fixed to a lewis to some part of the adjacent pier or arch ; the guide rope goes to an adjacent pier if raised to its height, or the next but one, if the next is not raised much above water. DH are a pair of blocks with two sheaves each, whose fall HIK goes to the jack roll or windless L, mounted upon a frame in the usual manner, and fixed upon some convenient part of the adjacent pier or arch : now as the roll drawing by the fall KIH, tends to draw the shears towards it, with a power of one exclusive of the purchase of the tackle, and as besides the fall there will be four parts of the rope acting as a purchase, the consequence will be, that the whole purchase will be as five to one, and the roll must gather up five yards of tackle fall to make the blocks DH advance one yard towards each other.

Again,

Again, the tackle blocks F will tend to draw the shears the contrary way to the other, and the tackle fall FMNO being attached to the under side of the roll L, this roller will command the shears either way by turning it one way or the other ; now to keep the two tackle falls thus brought to the roller at any equal tightness, or nearly so, it is necessary that the two purchases may be equal ; it therefore appears that if the fall ONMF, acting over the single pulley M, which serves only as a director, were simply attached to the block F, no power this way applied to the roll at L, would produce any action upon the shears, but only pull at the fixed part of the guide rope EF without producing any action any where. The blocks FG, therefore, must contain a purchase of five, and this will be done by making the block F treble, and the block G double, the standing part being fixed to the block H in like manner as the other standing part will be fixed to the block H. If, therefore, one fall is attached to one end of the roll, and the other to the other, while one is winding off, the other winding on, four feet in length, and six inches in diameter will be fully sufficient ; and the handle being of the same length as before prescribed, as one man will generally manage the matter, the handles will best be set opposite that they may simply balance each other.

To avoid all confusion of the figures, I have wholly omitted the main tackle blocks, which are suspended from the top of the shears ; and to avoid the platform of the work from being crowded, I suppose the fall for the main tackle to be returned from a snatch block fixed to a lewis, next the foot of one of the shear logs, and from thence passed to a main windlass or jack roll, and supposed to be placed upon the adjacent pier at P, or upon the arch near the other windlafs. Two men in ordinary cases being supposed to manage both windlasses, that is to assist each other in hoisting the stone perpendicularly, and then one of them to go to the guide tackle windlafs to overfet the shears, which done, the first can lower it by the main tackle.

The overlaying of the shears should be sufficient to clear the stones from rubbing and beating against the sides of the pier, while hoisting perpendicularly, and the feet of the shears may either stand upon the aisler or just behind it, so as to drop such stones into their places as come within their compass, and that on either side. The fall of the main tackle may be prevented from dipping in the water, in passing from pier to pier, by a small block being suspended from the guide rope at I.

The guide tackle blocks may be such as those made for shipping, the sheaves about six or seven inches.

J. SMEATON.

London,
27th March 1779.

To

To Mr. Pickernell.

Austhorpe, 25th Feb. 1780.

I have made up my mind respecting the north termination which I now enclose, and expect you will find it sufficiently intelligible. See plate 12. figs. 1. 2. 3. It is made conformably to an elevation on the same scale, shewing the elliptical and first segment arch from the north, sent to you in a former letter, describing the method of constructing the elliptical arch, where the cordon is described as laid down upon the key-stones, and to which I find I have not had regard in making out my design of the transverse sections, which was intended chiefly to shew the projections, by which means the whole parapet became raised six inches unnecessarily, and in consequence the thickness of the road gravel upon the top of the arches.

I am, &c.

J. SMEATON.

EXPLANATION of the Design for the North Termination of Hexham Bridge.

Plate 12. figs. 1. 2. 3.

THE line AB, shews the surface of the road to be inclined in the proportion of one in 12; and which is to meet

BC, fig. 1. The surface of the road over the first segment arch, which, if produced to the middle of the elliptical arch, will go to D.

The height of the road at B, the middle of the first pier above the springer, is as per section 17 feet, which being settled, it will pass about two feet eight inches above the soffit of the elliptical arch; that is, supposing it two feet in thickness, will allow eight inches for the gravel, and as much more as the stones in the middle of the arch are short of full two feet in the pier; and NB the exuberances, may be scapped off, so as not to hurt the general bearings, and give their all possible thickness for the gravel at F, the termination of the abutment walls, it will pass at or about nine feet ten inches above the top of the dooming, supposed the ground level at the line E, the extreme of the road wall pillars, extending from the extreme of the abutment walls 64 feet, it will

be four feet ten inches, that is nearly upon five feet at the center of the pillars from whence the road slopes away till it meets the natural ground, which, if perfectly level, will be at the distance of about 58 feet beyond the terminating pillars, and in this space the road is raised rampart fashion, being upheld by natural slopes on each side, like a common turnpike road.

The walking path is supposed to follow the line BD, and then keeping parallel to the top of the parapet D to G, there to descend two steps, upon the extended gravel surface between the abutment walls, where there will be room enough.

The same letters in the section, fig. 1. refer to the same parts as in the plan, and wherein the dotted lines HIKL, are supposed to be the hollowest part on each side for conducting the water, where the one in 12 slopes begins towards L, it will be proper to cross-sett this hollow with thin rubble, to prevent the sand and downfall of showers from getting a channel.

In the cross section, fig. 3. upon the line FFF, wherein

MM—Is the height of the springers.

NN—The top of the dooming or ground line.

OO—The main height of the surface of the road, being supposed a little swelled in the middle, and hollowed at the water courses, as before described.

PP—The line of the top of the abutment walls, and

QQ—The same.

Y s t o w x, is a section of the body of the termination walls, to be six feet high including capping: the inside of the capping ranges with the inside of the abutment walls, and the outside of the body of the termination walls, to be built with all the batter they can, so that the sloping face x w, does not go beyond the abutment wall of the top of the dooming.

The method of founding and building walls, and for founding the termination pillars, no part need be dug deeper than through the loose soil, perhaps one foot deep; but the

the bottom must be set with flat rubble lengthways cross upon the foundation trench; and when done to be driven down with paviours rammers: the body of the wall to be built dry, but at every half yard in height to lay on bond stones well bedded in mortar, at the distance of two yards from each other, middle and middle; observing, that in the course of bond stones next above, to put them at the middle spaces of the course below, so that there will be in event, a bond stone in every square yard of face; and as the bond stones may not be long enough to reach through the wall in one entire stone others must be laid to make good the bond quite through in mortar.

The body of the terminating walls to be built with something of care, in the style of a very good field wall, the cordon to be hammer-dressed, and reduced to a thickness; the stone to be found and laid in with a parapet to be of hammer-dressed stuff of promiscuous courses, from three to six inches both inside and out; built with mortar, and neatly walled like a farm-house. The capping to be of good sound stone, broached and well jointed, the terminating pillars hewn where octagonal, and not hid by earth, the square base walled and hammer-dressed on the sides that will appear, the foundation rubble in mortar.

J. SMEATON.

To Mr. Pickernell.

Sir,

London, 26th May 1780.

In regard to the mode of finishing the south termination from the south abutment, if the ground were as high it would be perfectly the same as the north; you are therefore to carry on the work so that all above that level shall be the same; the section of the walls therefore under that level will be no more than a continuance of the same section lines, observing to increase the thickness, not only by a continuance of the slope on the face, but by setting off on the back side; and as this continuance of the slope in part may make the foot to project considerably before the foundation of the main walls of the abutment, you may get rid of it by turning it a quarter round upon the abutment wall.

The declivity at top will be the same as the north end; and in this manner you may be going on till you come to the hollow, where I propose to have two arches of 18 feet span, with a pillar of at least six feet between. These arches are to occupy the deepest part of the hollow, so as to vend the water with the greatest advantage, and then to have an 18 feet arch from the same center over the mill leet, but separated from the other two by such walling as in length to suit the ground, and after you are over the mill leet, then to make

make a quarter turn, and terminate the walling with two termination pillars like those of the north end. I propose to make the 18 feet arches to rise four feet, so that you may be preparing the centering; and as the penstones may be from 18 inches to one foot, as they may happen to run promiscuously, you may be getting them prepared; they need no work upon them further than to bring them to a bearing. The work of the pillar and abutment walls of the arches, also need no other work than to make them course and joint; but the whole floor of the land arches I propose to be rough sett with flat rubble 18 inches in height or depth, to be just enough shaped with the hammer in setting to make them pack like a tolerable pavement. This to be extended about 15 feet below, and about five feet above the arches, apron fashion, and to be kept by ribbands or string pieces piled down. I mean to pile under the pier and abutment walls; but as this will be particularly described by the design, I now mention them to give you some idea of the materials that will be wanted for that part of the service. I don't however mean any piling or wood work but what will be got out of old stores.

In regard to the foundation of the terminating walls, I mean that part which you are now to proceed upon from the preceding directions, I believe the less you sink below the natural surface the less you will get into soft matter, so that you may rise and fall by steps according to your discretion; a foot into the ground, where the cover will be the least, I apprehend will be quite sufficient; this you are to cross sett, and drive down with a rammer, as directed for the north abutment; but if the matter on trial becomes soft, and in your judgement unfit to bear the weight, then you must drive promiscuous piles at about the rate of one in a square yard, more or less, as you judge necessary; but more rank near the front than the back side of the wall, and rough sett, and driven down between the heads, so that the heads and setting may be flush, upon which you are to build, filling the spaces of the paving with quick lime and gravel, in case it beats to a puddle: the most ordinary stuff will do for this service, that will bear driving; but get the piles down into a harder stratum, if you can.

I am, Sir,

J. SMEATON.

To Mr. Pickernell.

Sir,

Austhorpe, 28th October 1780.

I am sorry that any thing should have discomposed any part of the outworks of the bridge, though, as it turns out by your letter, it is nothing more than might be expected, whenever

whenever a top flood came, as before that nothing was ever stirred, and therefore the rubble not disposed as laid by the water; but as its effects seem to have been principally spent upon the fourth pier, I think it will be proper now to do with it what I have all along proposed in my own mind, in case an effect should take place to the degree you have described of that pier: that is, to drive some of the round oak piles about 18 inches distant, middle and middle, driving them down by fotts three feet under the common low water surface: the point pile being advanced up stream about 15, or, if you please, 20 feet above the salient point of the casing: the line of the piles to be made a little rounding, I think the upper side is the better figure. The internal space between the piles and the casing to be filled with rubble, as large as you can well get it, and some large pieces to be chocked in between the shoulders of the casing and the shoulder piles, and then filled up with smaller at the top. I would also lay a ~~loose~~ ^{loose} slope of rubble upon the outside of the piles, to be reconciled with the footing slope on the side of the cases. As it appears from all the arches interspaces wearing deeper, that it is the natural effect of the waters being more confined than at first by the interposition of the piers; it therefore indicates, that we should not fill up more than what is absolutely necessary for our security; for the more we block up the more tendency the water will have to take away the blocking and deepen the interspaces. You have not given me the soundings in the respective interspaces, nor told me where the rubble, &c. is chiefly lodged below the tail of the piers; if I were informed of these matters, as also whether the deepening of the interspaces was greater at the east or the west shoulders, or below the east shoulders, I should be able to tell how to direct you. You mention however that your soundings by the side of the fourth pier were eight feet; now if all lies regular, I shall not think eight feet too great a depth in the middle between the piers; and if the rubble slopes do not reach within three feet of the top of the casings, extending above two feet in base to one of perpendicular height of the slope above the casings, it will be as sufficient as if higher and broader.

Nothing will so much tend to give an easy passage to the water through the bridge, as its spreading equally through all the arches. The beating jetee on the north side, greatly tends to prevent the water passing freely through the north arches, at the same time that it throws it upon the center one; that therefore should not only be removed, but the shore made smooth and regular, the ground and all impediments removed from the north elliptical arch, and the rising ground below it taken away; for if the water is stoppt below an arch it is an equal impediment to the waters getting through it as if under it or above; and whatever is there stopped must be thrown upon some other, and the water naturally tends to find its passage where it finds the least obstruction:

the

that is, where the channel is the deepest. Our business is therefore as much as possible to invite the water through the side arches by smoothing and clearing all impediments to its passage through the same.

I am, &c.

J. SMEATON.

To Mr. Errington.

Sir,

In answer to your request, desiring my opinion in writing concerning the late calamitous accident at the Bridge of Hexham, and that it is most adviseable to be done upon it; I must, in the first place, observe to you that from reflecting upon every circumstance that has yet been communicated to me with all the precision I am able, I am of opinion that the true cause of any failure was occasioned, not only by the great violence where-with the bridge was attacked, but by the great weakness of the stratum of matter that lies immediately under the bed of the river, and which has been said universally to prevail in that neighbourhood by those who made trial thereof, between the building of the first bridge and that of the second; which weakness of the under stratum I was not only aware of, but turned my thoughts towards every expedient that could tend to avert the ill effects that might arise therefrom; and having observed, that in all the attempts of those who had gone before me in this enterprize, they had dug considerably into the bed of the river, and thereby rendered that weaker which was already too weak, I did not doubt but that, by a contrary practice, my endeavours would have been crowned with the wished and expected success; for as I had read of buildings and bridges that had stood upon more weak natural foundations than this appeared to be, and even myself had a case of the kind, that I had effectually remedied, I did not doubt, but that with the precaution of not weakening the upper crust of hard gravel, but building immediately upon it, I should in like manner succeed in this place.

The instances, however, that had come to my knowledge, though the strata under the foundations might be naturally weaker, yet none of them are liable to be attacked with any thing near that degree of violence that this river now appears to be capable of; had it been possible for me to have been acquainted before hand that a flood of this river could come down with so much suddenness, as that, for want of time, for the lower reaches of the river to be filled from the upper, there could be created a fall or difference of level between the up stream end and the down stream salient point of the same pillar, of no less than five feet perpendicular, which would in effect create a velocity

velocity of the water of above a thousand feet in a minute; I say, could I have been informed of this single fact, as appeared to be at, and for some time before any degree of derangement was apparent in this bridge, I never could have thought of advising you, or any private gentleman, to have undertaken, at his own risk, a building of so much danger and hazard; and, exclusively of that danger and derangement which might naturally be expected to arise from the mere rapidity of the water, I am further of opinion from what now appears, that the mere difference of the weight of the body of water immediately above the bridge, which could not be counterbalanced by a body of water of an equal breadth immediately below, has, in reality, been sufficient to force down the under soft stratum out of its former position, so as to be more inclined to the west, and occasioned the upper stratum, upon which the bridge immediately stood, to follow it; and in both these respects, that is, of rapidity and unequal pressure upon the bottom, the violence would be greater than even in the great inundation of 1771; for though, according to accounts, the height of that was greater, yet its rise was far less sudden; and therefore its rapidity and tendency to derangement less.

To the question, What is now to be done? I answer, that though I do not conceive it impossible to re-erect the bridge in the former site, and where much expense is standing towards a completion; yet I do conceive it impossible to be done with any reasonable hope of its proving a permanent or successful undertaking. I am further fully convinced the bridge was perfectly safe against all common occurrences.

I remain, Sir,

Gray's Inn,
6th April 1782.

Your most humble servant,

J. SMEATON.

P. S. The bridge I mentioned to have restored was the Bridge of Dumbarton, about 20 miles from Glasgow, undertaken by government. That part of it that failed was built upon a crust of gravel not above two feet thick; and, without any flood, external violence, or previous notice, one of the pillars went down, with the two adjacent arches, and crushed the centers, then standing, under them. On examining, I found the ground so soft under this crust of gravel, that a bar of 40 feet went down to the head by its own weight.

To

To Mr. Pickernell.

Dear Sir,

Austhorpe, 6th June 1782.

Our honours are now in the dust! It cannot now be said, that in the course of thirty years practice, and engaged in some of the most difficult enterprizes, not one of Smeaton's works has failed: Hexham Bridge is a melancholy witness to the contrary; yet, after all, I feel much less for honour and credit than I do for the actual loss sustained by Mr. Errington: it would give me much satisfaction if that matter were settled between him and the county. I have heard that his appearance there at the Easter sessions much inclined the magistrates to see the matter in a favourable light; but the difficulty was, how far it was in their power.

I saw Mr. Donkin in town, who assured me, that he was looking at it when it first appeared to give way; his son being but just returned from the south side, to see that the small arches there were safe, which was the only part that they had any doubt about. He was wondering at the possibility that any structure could withstand such extreme violence, yet not at all expecting that any thing would hurt it; and remarked that before any thing appeared to give way, the water was up to the top of the doom-ing of the piers up stream when it scarcely touched the bottom of the impost down stream, which makes a fall of five feet, and it was not above a couple of minutes between first perceiving the mortar dropping out of the joints of the soffit and the fall of the arch, and six more were down in half an hour, so that it was so equally guarded that in a manner it all went together. Could I have known beforehand that there was a possibility of a flood to come down so suddenly ■ to have made a fall through all those extensive openings of five feet, I should certainly never have attempted the building a bridge in that situation, as that fall would necessarily create a velocity to the water in its passage of 1100 feet per minute: a velocity that it would require the strongest sluice-floor and aprons to withstand. I am therefore clear that it has forced away the very bed of the river and all before it. The occasion of this extreme suddenness in the waters coming down, which in that respect was far greater, according to all accounts, than in the great inundation of 1771, though the total height not so great, was, doubtless, owing to this circumstance, that the afternoon before ■ very great downfall of snow happened, so deep as to cover the ground at an average two feet. This was immediately succeeded by a vast downfall of rain, none of which would run off, till the whole body of snow was saturated like a sponge, and then, like the bursting of a snow-ball in the fire, it would come down all at once, and that so suddenly, that the lower reaches of the river not having time to be filled from the upper, they would be comparatively empty; and as the velocity of water depends upon its fall, or difference of level at any given place, and not upon its total height, the difference will depend

depend upon the suddenness of its coming down; and this being further hurried down by a violent gale of wind at north-west, the very direction that, upon the whole, would tend to bring it down the quickest from both the Tynes, it would seem as if all the powers of nature were collected to humble my pride and yours. The news came to me like a thunderbolt; as it was a stroke I least expected, and even yet can scarcely form a practical belief of its reality. A flood that could mount up to the top of the doomings of the piers was, however, not a small, or even middling flood, in point of height; and as every object that entangled it would moderate its rapidity, it is not improbable but that the downfall of Hexham Bridge might be the saving of Corbridge; and by the spreading gradually over the wide haughs in many places below, was not more than a moderately large flood at Newcastle. There is, however, one consolation that attends this great misfortune, and that is, that I cannot see that any body is really to blame, or that any body is blamed: we all did our best, according to what appeared; and all the experience I have gained is, not to attempt a bridge upon a gravel bottom in a river subject to such violent rapidity.

I remain, your most humble servant,

J. SMEATON.

P. S. I cannot suppose any failure arising from the greenness of the work, but wholly from the whole bed of the river giving way under it; as nothing appeared to settle till it gave way in a manner at once, which is a proof of its being firmly bonded together.

A COPY of Mr. Mylne's Opinion and Report, delivered to the Magistrates of Northumberland, respecting the Practicability of building a permanent Bridge at Hexham, on the Site of that built by H. Errington, Esq.

Hexham, April 24th 1783.

To the Magistrates and Justices of the Peace in and for the County of Northumberland, in General Meeting assembled.

Gentlemen,

BEING requested by you to view and examine the present state of the Bridge across the river Tyne, lately built by, and at the expense of Henry Errington, Esq., agreeably to the plan and advice of Mr. Smeaton, and to inspect the site and nature of the bed of the

the river, whereon the same was constructed, I beg leave to report, that it fully appears, this bridge was undermined by the great flood, which happened on the eleventh day of March 1782, and that the soil and substance of the bed of the river, of whatever matter and quality the same consisted, was dug or scooped out from below the greatest part of the piers, and *that* towards the west or upper side of the bridge,—and the advanced or guard works, inclosing a space round the piers, for the better security and maintenance of the soil immediately under the piers, whereon the whole weight of the structure had been charged, were also undermined by the gravel and sand, into which they had been driven, being worn away by the velocity of the stream; thus circumstanced during the height and greatest rage of a flood, it will appear no wonder that the piers, having a fourth, half, and even to three-fourths of their base taken out from below them, the arches split in two longways, by some of the piers breaking across, into two parts, precipitated into ruin themselves, and the parts constructed upon them.

All the piers fell towards the stream, but took different inclinations towards the excavation of the bottom, sometimes made more on one shoulder than on the other of each pier.

The surface of the water-line is now twenty-two inches lower than in the time during which the bridge was constructed; I have bored the river at the bridge to the depth of twenty-three feet below the latter water level, in a place where I might not be led astray by any alteration formed by the said flood, in the height of its impetuosity; and skimmed over again in its milder velocity; and I have found under the testimony and perseverance of Mr. Wake, that the soil and texture of the bed of the river at this place, is uniformly a composition or congeries of roundish and flat stones, gravel and sand, of equal quality and consistence in the whole of that depth.

The piers which were founded by means of a batter d'eaux, have stood tolerably well, and those which were laid by caissons, having no piles directly under the piers, were the easiest prey to the vast powers of this flood.

The depth to which all the works in general, whether immediate or preservative, were carried was far too shallow, and too little into the bed of the river, which (though hard to the touch of boring and compact to the eye, and feeling of instruments) is wonderfully loose, and unconnected in its parts, in so much, that the bed of the river Tyne seems to shift and alter its form, extent and situation, with every flood more or less, and tearing up at one time to a great depth, that fair moulded and well laid hollow, which the stream had laid for itself on some former occasion.

In such a situation, under these circumstances, with the additional one of many piers being to be fixed as obstacles to its violence, the foundations could not be laid too low. To what depth they ought to have been laid, and the means to be devised for that purpose, lay and remain with the parties engaged in the performance.

Mr. Smeaton, than whom there is no person or artist better instructed, more knowing, and of a more penetrating and correct judgment, must have been deceived in the collection of facts and materials, on which he established his plan of operations.

A great mind is often deceived by its own virtues. Habituated to give, on all occasions, the genuine and honest productions of its faculties, it often relies too much, and implicitly, on that which appears to be the ~~same~~ of other persons.

The existence of a sand below, and a supposed hardness and concretion of five feet or any such measure of the upper parts, seem to have precipitately and fatally determined the plan of operations, at first setting off, and appear to me to be equally the cause of the present precipitate opinion, for abandoning the proposition as impracticable.

Art furnishes the means, I humbly presume, of going to a sufficient depth, with all the foundations, and that too, on the spot, notwithstanding the damage which this site has received.

To compare the eligibility of this situation with that of any other near to Hexham, and the direction of the Alenmouth road, is perhaps useless to discuss at present.—But in my opinion, if nothing had hitherto been done, (as too much has unfortunately been done) *I would have recommended a place of deep water, and fixed elevated banks, like to that opposite to the west end of the dwarf wall of the Spital Green within Mr. Wastell's inclosures.

To enable me to form the opinions, which I have now the honour to report to you, I have seen and examined all Mr. Smeaton's papers, I have heard all the particulars, and history of his proceedings, and motives for the method of operations which he adopted, I have examined every part of the works, and many persons concerned, and employed in the detail of its execution; and it was my lot to pass here in August 1778, when I viewed the effects then produced, in those very foundations, by floods previous to that time, making for my own instruction, minutes of what then I saw.—I mention these things to enable you to judge of that reliance, you and all other parties interested in this business, may be pleased to give to these opinions, and to this report, which is made by

Your most obedient, and very humble servant,

ROBERT MYLNE

Mr. SMEATON'S Memorial concerning Hexham Bridge.

WHEN Mr. Smeaton was applied to by Mr. Errington, for the building of Hexham Bridge, it was not till after the total destruction of a bridge at the west end of Tyne Green, near that place, built under the patronage of Sir Walter Blackett; which, about twelve or fourteen months after it was finished, was totally destroyed by an extraordinary flood, that has ever since been distinguished by the name of the Great Inundation, which happened in November 1771; but as this bridge was standing at dark in the evening, and totally demolished the next morning, no other information could be drawn from this very fatal and alarming accident, but that this river was capable at times, from a certain combination of causes, of being swelled to a degree of violence far exceeding any thing that had before this been experienced, handed down by tradition, or imagined.

As an evidence of this, amongst many others that might be given, the water rose seven or eight feet, or thereabout, upon the main ground floor of Mr. Fenwick's new-built apartments at Bywell; which being erected from the designs of that eminent architect Mr. Payne, it is not likely that he would direct the main floor to be laid within flood-mark, as it had, at that time, been known, or then thought likely to happen; and yet, Bywell being many miles below the junction of the two Tynes (that is of the North and South Tyne, about a mile above Hexham) and after it had had much room to spread over the wide haughs that laid between Hexham and Corbridge, and also in the space between Corbridge and Bywell, we must conclude, that the rise of the water was less at Bywell than in the neighbourhood of Hexham.

Under this degree of information, and experience of the utility of a bridge at Hexham, (Sir Walter Blackett having chosen rather to forfeit the penalty of a bond of three thousand pounds, that he had laid himself under for the upholding thereof, than attempt to rebuild or re-establish the bridge), the erection was taken up by the county; and, for this purpose, consulted that eminent engineer Mr. Wooller, then engaged for the town of Newcastle, in the re-establishment of Tyne Bridge there, so far as the magistrates of that town were concerned therewith, and (which through the Fan down the river, and in the tides-way, suffered also an almost total demolition) Mr. Wooller, on faith of borings made by a surveyor, a person employed by the magistrates of the county for that purpose, who reported, that a bed of clay laid at no more than four feet under the bed of the river, at a place about fifty yards above, or westward of the bridge built by Sir Walter Blackett, formed a proper design

design for building a bridge upon the foundation described, upon the principles of piling and planking under the piers, and which was begun accordingly in the year 1774; and, after building the north land-breast, Mr. Pickernell was recommended in the year 1775 to the county, by Mr. Wooler, and employed as surveyor under him for the erection of this bridge; who having sunk the foundation pit for the first pier from the north abutment, as directed, to the depth of four feet below the bed of the river, to find the bed of clay; instead thereof, came to a stratum of a very different nature, which, after examining, he reported to Mr. Wooler, then at Hull, viz. "A quicksand full of bubbly springs, and of so loose a texture, that by hand only, a bar of iron entered into it forty-six feet without meeting any resistance; and that a trial pile of whole timber entered twenty-six feet, at two inches and a half per stroke of the ram without sloping; and that the gentlemen concerned were eye-witnesses to the facts."

Upon the above report Mr. Wooler declared his opinion, that the attempting to set a bridge upon such an enormous depth of quicksand, over a river so subject to great floods as the Tyne, may be deemed so hazardous, as to be next to imprudence itself — and again, that this wretched quicksand, rendered the attempting a bridge on such principles (that is piling and planking under the piers) little better than folly — a quicksand, which, from its resistance to the iron bar, cannot be deemed much better than a heap of chaff. For, says he, "let it again be supposed, that a flood like that which overturned the late bridge should happen, it cannot be doubted, that when the loose gravel under the bed of the river (only four feet thick) shall be swept away between any of the piers, the quicksand under it will presently follow like water itself; and an excavation may be made in a few hours, as deep or deeper than any of the piles that guard the piers; when a downfall must be the immediate consequence. On these principles therefore, the bridge ought not to be attempted in this spot; and, if no better can be found in any other situation, there is but one method of dealing with such ground, which has succeeded where expense was not regarded: that is, by carrying a solid wall quite through the river, from side to side, about six feet high; and in this case it must be forty-two feet broad." The preceding extracts are made from a copy of Mr. Wooler's letter of the 19th of July, 1775, to Mr. Pickernell; the perusal of which will more amply set forth the grounds and reasons of Mr. Wooler's opinion; that no bridge under such circumstance, is likely to be accomplished at any limited expense; he concludes with saying, "I had the honour to mention this method (that is of the solid wall) to Mr. Aynsley, when there was a doubt about the nature of the ground, sometime before their surveyor found out the stratum of the clay; but he then looked upon the expense to exceed their abilities; but however, after all, if ever a stable bridge"

"made

"made there, I do not know any other means to effect it — You will lay this before the gentlemen for their consideration."

After this, Mr. Pickernell proceeded to sink a well or shaft in the solid soil of Tyne Green, near the place where the south abutment of the intended bridge was to be; when passing through the stratum of gravel, found the quicksand at nearly the same depth, (that is to say, four feet below the bed of the river) as in the foundation pit for the pier on the other side, into which he thrust his iron bar as before, and covered up the shaft, till Mr. Wooler should come and examine the premises.

He also proceeded to try the river, boring in other places; and particularly in the pool below the east boat; that is, above the place where Mr. Smeaton afterwards pitched upon, to build a bridge at Mr. Errington; an account of which boring being transmitted by Mr. Pickernell to the clerk of the peace, reference being thereto had, will more fully appear; but which went to prove, that whenever Mr. Pickernell had penetrated the bed of gravel, universally a stratum of quicksand was found.

Under these circumstances Mr. Wooler attended at Hexham, to survey the premises; and in the presence of some of the magistrates assembled on the occasion, repeated the trial of the bar, both in the foundation pit near the north, and in the shaft near the south-end of the intended bridge, and which succeeded as before mentioned. The existence of a stratum of quicksand under a bed of gravel in this place, then, does not depend upon the simple testimony of Mr. Pickernell, but is alike witnessed by very respectable, as well as competent judges.

The result of which view and survey was, that no other place appearing more eligible and likely, than where the beginning had been made, and being unwilling to go on upon the principle intended and began, of piling and planking under the piers; and the magistrates not giving ear to the solid wall proposed by Mr. Wooler (across and under the whole bed of the river, from side to side, as an artificial foundation whereon a bridge was to be erected), on account of the expense thereof, which was not likely to be uncertain, but so great as to be very imprudent for even the county to enter upon, the whole undertaking was at that time given up or suspended: and Mr. Wooler having been urged, as too easily desisting from his original plan, on going away, he very sagaciously and prophetically said, whoever meddled with a bridge there, would burn their fingers. After this the gentlemen of the county, unwilling to lose sight of a bridge at Hexham, an advertisement soon after appeared in all the Newcastle newspapers, as from the bench of magistrates of the county

county, importing an invitation to all adventurers to undertake the erection of a bridge, taking the risque of making a foundation upon themselves, and taking their own method of doing it, but to build the superstructure according to a certain design to be produced to them, and security for the permanency of the whole for the term of seven years. This advertisement was continued till the latter end of the year 1776, in which interval several adventurers had in succession offered, but all of them on a closer view, before the completion of a contract, started off; several expensive preparations having been made at the expense of the county, and the materials lying upon their hands: this work being therefore, as will appear from what is preceding, generally considered as a derelict scheme, or at least a forlorn hope; some time in the latter end of the year 1776, Mr. Donkin, agent of Mr. Errington, came to Mr. Smeaton in Mr. Errington's name, to know if he would undertake the direction of building a bridge over the Tyne, somewhere between the Lowford, and the Eastboat at Hexham, for Mr. Errington, provided he (Mr. Smeaton) could find a place for the founding thereof which he thought so sufficient, as that he would risque his credit upon it as an artist: in which case, if it could be done upon a moderate estimate, he (Mr. Errington) would make a proposal for building it to the county; urging, that as the county had been so long baffled in the attempt, as it would be an advantage to his estate, if it could be done there, it was probable that if it could be done at a moderate expense, the county might accept of a bridge there, rather than none, and if he (Mr. Errington) was two or three hundred pounds out of pocket on the above account, he would think it worth his while.

Mr. Smeaton, being somewhat surprized at the uncommonness and newness of the proposal, desired time to consider of it, as previously to that time, he had studiously avoided having any thing to do with it; though he had been frequently in that neighbourhood for a course of years, comprehending, and even preceding, the time of first undertaking thereof by Sir Walter Blackett; but considering it on this occasion as a great advantage to the public, that if that could be done which they then seemed unlikely to get done; he began to consider the causes of failure in those that preceded, and in thinking seriously of the subject, there occurred to him a mode of construction, that could not only be executed for a very moderate expense, considering the extent of the subject; but the only mode in which a bridge could be executed, on such a kind of foundation as was then generally supposed, at any moderate expense and with a reasonable prospect of safety.

This considered, Mr. Smeaton acquainted Mr. Donkin, that he was willing to examine the situation; and if he found it competent, so that he could hazard his credit as an artist

upon it, he would be willing to give Mr. Errington an estimate. The trial was made, ~~made~~ by Mr. Pickernell, who on this occasion recounted the principal part of what is related, so far as he was concerned; the estimate was made, presented and accepted, the bridge undertaken, built, and suffered the fatal overthrow that has occasioned the present litigation.

The preceding narrative will sufficiently show, that none of the parties pressed themselves into this unfortunate, this ill-fated business, or proceeded in it from any interested motives.

Respecting Mr. Errington, he neither professed nor could ever have any view of profit from the undertaking, the only benefit that it might in that situation be to his estate, being the sole motive of pains and trouble that must necessarily attend it.

Respecting Mr. Smeaton, he neither asked, expected, sought, nor received more than his accustomed daily hire, and he trusts, that it will not be supposed, that he could wish to undertake this business for want of employ; and in respect of Mr. Pickernell, if he wanted employ, he would have been much more likely to have met with it, by the bridge being proceeded with, if he had reported a good gravel to an unfathomable depth, knowing or believing there was a quicksand at nine or ten feet under it, than he could expect from reporting a quicksand, at nine or ten feet under the surface of the gravel, knowing or believing it was gravel unfathomable; because being then not at all acquainted with Mr. Smeaton's ideas of the proper method of treating such a subject, he must suppose it more likely for a bridge to be undertaken and proceeded with, if the foundation was a gravel unfathomable, than if it was a gravel with a quicksand under it.

What remain, therefore, as questions material to the county and to all the parties, seem to be the following, and what they who undertake to judge of the whole matter, should be acquainted with.

1st, Whether Mr. Smeaton from the whole matter before him, at the time of forming his project, did it with that deliberate judgment and reasonable probability of success, that have characterized him in other things?

2dly, Whether

2dly, Whether Mr. Errington was sparing of any thing necessary to give success to that mode of building which Mr. Smeaton had adopted?

3dly, Whether Mr. Pickernell did to the best of his power and abilities execute, to a reasonable and possible extent, what he was directed by Mr. Smeaton?

4thly, Whether under all the experience and knowledge of the subject, as it now stands, the present bridge should be attempted to be re-instated, or a new one built at Hexham?

With respect to Mr. Smeaton's scheme for the bridge, the following matters are worthy of observation:

1st, That from the failure of Sir Walter's bridge in the night, no estimate could be formed, of the fall or velocity that the water had in passing that bridge, at the extreme of the flood, before its failure: for though the marks of the flood were left very visible, which shewed it to have risen many feet higher than any former flood, in point of height; yet this gives no light into the stress laid upon the bridge by the velocity of the water, for no bridge, even tolerably built, ought to suffer from the water's rising any height upon it whatever, if stagnant or rising very slowly, by the counteracting of a rising tide opposing the natural current.

2dly, That it is ascertained beyond a doubt, that at the place where Mr. Wooler began, there in reality existed a quicksand of an unfathomable depth, covered with a bed of gravel, of a very moderate thickness and consistence, and intermixed with large tumbling white stones.

3dly, That not only from the faith of Mr. Pickernell's subsequent borings, but from the proximity of the two situations (not one-third of the breadth of the river asunder), it appeared in the highest degree probable, that the same, or some such a stratum of loose matter, lay under the foundation of the bridge built by Sir Walter Blackett, and was the cause of its destruction; otherwise, its sudden and total destruction, in so short a space of time, was to Mr. Smeaton totally unaccountable; who in the way of curiosity (as other business often carried him to Hexham) had sometimes viewed the operations of that bridge while it was building: that bridge having been in his judgment at that time competently well founded to guard against accidents, considering in what manner

it

it was done, when compared with the manner of founding on gravel used by our forefathers; and which, for Sir Walter Blackett, was designed and undertaken at the risk of that ingenious and well experienced builder Mr. John Gott, of Woodhall, in the West-Riding of the County of York, who for several years previous to that, had been undertaker of the building and repairs of the county bridges in the said West-Riding, and also surveyor of the rebuilding and repairs of the navigation works upon the rivers Aire and Calder; a man rendered truly respectable to all who knew him, from a long series of successful experience in this kind of arduous undertakings; and who, moreover, previously to this undertaking at Hexham, had with great success and credit to himself, then undertaken and completed the new bridge at Ferrybridge, in Yorkshire, which was done upon the self same principles that he afterwards put in practice upon the Tyne, and which bridge still stands unhurt upon the river Aire (there also united with the large river Calder) to the praise of the skill of the worthy builder thereof.

This person, Mr. Gott, being personally known to Sir Walter Blackett, as well as his works, Sir Walter pitched upon him as a proper person to ensure success to his favourite project; and still the more effectually to do it, he joined with Mr. Gott, Mr. Brown, a very worthy and experienced mason of the neighbourhood; a person that had acquitted himself by many works done for Sir Walter and others, and some in the bridge way, and was also at that time surveyor for the bridges of the county of Northumberland: and still the further to secure their care and industry in this undertaking, he had them bound to him as undertakers for the sum for which they contracted with him, to uphold their works for the term in which he stood engaged to the county; but as a demonstration, that shews how well he was satisfied, that the care and skill of the undertakers were fully and properly exerted, he, after the accident and a full examination, gave them up the bond they had entered into with him, contenting himself to pay the penalty in which he stood engaged to the county.

And now, as it will throw a considerable light upon what I have to say further upon the subject, it will not be lost time to explain the mode of founding, adopted and put in practice by Mr. Gott, as it appeared to Mr. Smeaton by ocular inspection, and who at the time was acquainted with the undertakers, but more particularly and previously with Mr. Gott.

Having constructed large and broad coffer dams of earth to fence off the water, by the help of chain pumps, they sank the foundation pit about three feet into it; then they drove piles over the whole area of the intended foundation of ~~car~~ from ten to twelve feet long, and from ten to twelve inches diameter in the heads, and tapering according to the natural taper of the timber, proper for driving into gravel of considerable resistance. The heads being cut to a level, the whole was covered by a platform, made of whole (that is twelve inches) Riga barks, rabbetted or halved into each other, so that each could not subside without its neighbour going with it, and upon this platform the pillars were respectively built.

Mr. Smeaton has reason to believe (though he never happened to be there when any piles were driving), that the undertakers finding their piles go into the ground more easily than they expected, and the upper part the hardest, did not in all the pillars make the excavation of the foundation pit quite so deep as above mentioned, but yet all were founded below the bed of the river: and, in a conversation with Sir Walter Blackett, after the founding the bridge was done, Sir Walter observing to Mr. Smeaton, that a rumour had gone forth, that the founding of the bridge had not been made sufficiently strong, Mr. Smeaton said, that had they increased the circumference with plank or sheet piling, as he had done in all the gravel foundations of the kind, that he had had the ordering of, it was all he should have done more than was done; but as the laying a solid platform, and even the piling itself, were things that our forefathers had not generally practised in such cases, and yet we found many of their bridges standing after many years trial; it must be something very extraordinary that could hurt a foundation so laid, far beyond any thing wherewith we were then acquainted.

This serves to shew what the opinion of Mr. Smeaton was at that time, before any derangement had happened, so that it was a matter to him of very great surprize, that notwithstanding the extraordinary height of the water, a bridge so founded should be so entirely demolished in so small a space of time; but when the operations of Mr. Wooler were known, his surprize ceased: looking upon it as a certainty, that the violence of the water having taken off the crust of gravel, wounded also by the excavation for the piers, so as to let loose the quicksand, he no longer wondered at the sudden demolition of the bridge.

The third matter to be observed is, that Mr. Smeaton had at that time, (that is, at Mr. Donkin's application) finished with success two capital bridges in Scotland, over

two of the reputed most rapid rivers of their magnitude in that part of Great Britain; that is, over the Tweed at Coldstream, which was finished about the year 1767, and the Tay at Perth, which was finished in or about the year 1770, and which in the interim before Mr. Donkin's application, had sustained many severe attacks from floods, but without any injury, except (in some slight degree) to the rough rubble stone deposited round the piers by way of defence, and which being occasionally replaced, the whole remained and does still remain unhurt.

These bridges, the first being in part, and the latter wholly upon gravel of unfathomable depth, were founded on bearing piles, encased with sheet or plank piles, below the bed of the river, the space being filled up, and the foundation farther defended by the deposition of rough quarry rubble stones: and Mr. Smeaton having experienced the great dependence and power of resistance of stones so deposited, not only in the cases of building the bridges above mentioned, but in a great variety of cases, preceding those undertakings as well as after, wherein he found them the most effectual means, not only of controuling the violence of rapid rivers, but of the sea itself, he was naturally led to place very great confidence in that species of defence.

4thly, That partly from the report of Mr. Pickernell's borings, partly from the similarity of situation of the place proposed by Mr. Errington, to that where Sir Walter Blackett and Mr. Wooler had worked, being both of them near the bottom of an extensive pool, wherein the water is kept up by a bed of gravel just below them, and forming as it were a natural dam, whereby the motion of the water in the pool above, in the low state of the river, was scarcely perceptible; I say, from similarity of situations, Mr. Pickernell's report of the ground, just above the place pitched upon by Mr. Smeaton, and the trials that he (Mr. Smeaton) made himself, by driving a sharpened iron bar from nine to ten feet into the bed of the river in several places, which was very considerably less resisted, and particularly in the main current, after it was driven down some feet, than it was in entering the upper crust of the gravel bed, which was apparent to him, by his assisting personally in the operation; from all these considerations he thought himself well justified in concluding, that at some depth, exceeding nine or ten feet, at this place, there either actually existed a stratum of quicksand, similar to that at the west end of Tyne Green, or at least matter so little compact or capable of bearing weight, that to drive piles into it would only weaken the stratum. The question therefore, that he had to decide for his own guidance was, Whether there was a bed of gravel of sufficient thickness and compactness to bear the weight of a bridge, in case it was unwounded and unbroken? And the experiment of the bar abovementioned (which

(which was tried in several places across the river), determined his judgment, that what he had felt and experienced was sufficient.

It may here naturally be enquired, why Mr. Smeaton did not bore the bed of the river, instead of driving the bar in the manner described? and he answers, because former experience had taught him to have very little faith in boring in gravel, for the purpose of founding bridges; for the colliery borers, though exceedingly expert in boring for the purposes to which they are to apply them, yet are no competent judges of the compactness of the stratum for the purpose of building a bridge; and in the trials formerly made by Mr. Smeaton himself, from the continual falling in of the smaller parts of the gravel itself, while the boring instrument is turning round, thereby occasioning a continual grinding; and if the instrument is attempted to be withdrawn, the holes immediately filling, made it never appear to him in the light of a satisfactory operation, convincing to his mind of any certain conclusion: he has therefore, for many years past, contented himself with trials by the bar, which being driven by a hammer, he judges of the compactness of the gravel, by the number and strength of the blows that it takes to go down; and on the faith of trials of this kind, where the bar went down with a competent resistance and a near equality, he built the bridge of Perth upon piles encased with sheeting.

From a mature consideration of the above particulars and circumstances, Mr. Smeaton found himself led to the following conclusions, viz.

That to build a solid wall across the river as a foundation for the whole bridge, in the manner proposed by Mr. Wooller, would not only be attended with an enormous expense, but, in the place where he proposed it, likely to be in itself impracticable: for it did not, nor does it occur to Mr. Smeaton, how this is to be done without draining off the water from the bottom of the very large excavation that would be necessary to be laid open at once; which must not only go down to the quicksand, but in reality considerably into it, to lay the proposed foundation of the wall; that in case the quicksands should break up and run, as it was most likely to do, the drainage of this liquid matter would be endless; and if any part of it was attended with so much success as to get founded, yet the part so founded would be sapped, when the sand is so broken up in any succeeding part.

That though in the place pitched upon by Mr. Smeaton, the bed of gravel appeared both thicker and firmer than where Mr. Wooller had begun; yet, as it appears evidently

dently to him, was likely to partake of the same quality, the execution of the scheme of a solid wall, or of penning as proposed by others (to make which effectual must be to the same thing) could not be done upon any limited estimate; and at any rate would exceed all bounds of expense, that it appeared to him likely or indeed prudent to be gone into by the county.

That to attempt the building of the bridge upon the principles of that of Perth; that is, to sink an excavation pit considerably into the bed of the river, and in this to pile and encase, would be, in effect, first to destroy the very best and firmest part of the stratum, and then by driving piles into what was likely to be incapable of bearing the weight, would be in reality to repeat the errors, that, as it seemed to him, had been committed in Mr. Gott's erection; and as, last of all, the security of the bridge in any of these methods, must ultimately depend upon the defences to be made by the judicious and proper deposition of rough quarry rubble; it appeared to him a folly, first to destroy the firm upper crust of gravel that he reported verbally on his trial thereof to be comparatively hard, like the pavement of Hexham streets, and then, at a great expense, substitute something not so much to be depended on, and this still want defending by quarry rubble, which in every case could be applied: and he must here beg leave to remark, that a quarry, situated most commodiously to this situation of the bridge in the estate of Mr. Errington, offered the greatest plenty of this kind of material, and of the most excellent quality for the purpose that he has any where had the experience of.

From the whole of the premises he concluded, that the safest way would be to preserve the upper crust of the bed of gravel inviolably unbroken even by a pile; and particularly in the main channel of the river, where the diminution of the hardness of the upper crust principally to him appeared; so that, concluding to build the two land-breasts upon piles, with casting, and also the two pillars next thereto, in the same method, with coffer dams to drain out the water (he having found that within that compass the bed of gravel appeared equally hard and compact) the method that naturally offered itself was to found the rest of the piers by caisson; a method the most easy and ready, and attended with the least cost of any. So that having before abundantly experienced that good quarry rubble would resist the action of a current to a greater degree than any kind of gravel, it appeared that the pillars so sunk, being defended from accidental flood till they could be surrounded by a slope of rubble (which the depth of the water naturally admitted in this place) hence would arise every degree of security that the nature of the subject would admit of.

He concluded therefore to build a bridge of nine arches instead of seven, that it might have more legs to stand upon, in consequence of the natural weakness of the stratum; and by way of security to the piers, before they could be properly and sufficiently surrounded by the proposed slope of rubble, as well as after, in case of any derangement to the rubble defence, a girdle of stones in blocks of a ton weight and upwards, was proposed to be let down, and surround the base of each pier, to be fitted to each other, and to the pier they surrounded, and to be cramped together.

Upon this idea of construction Mr. Smeaton formed his original estimate; and which, from the simple mode of it, could be executed for a very moderate sum of money, in proportion to the largeness of the river and extent of the work; and which, in consequence, was bargained for by Mr. Errington, and the work proceeded with accordingly.

The north land-breast and the adjoining pier were successfully built upon piles encased as proposed; and the gravel being there very sufficiently compact (so as to afford only a moderate quantity of water) Mr. Smeaton determined to try to go on as far as he could upon that principle, and therefore ordered the second pier from the north abutment to be tried with a coffer dam, to encavate and found like the first; but when the pit was sunk but two feet under the level of the water outside, and not much more than half as much under the natural bed of the river, the water boiled up between the interstices of the gravel stones, bringing sand along with it, that it required forty men continually at the pumps to keep it down; and it was not without the utmost difficulty that the pier was founded on that principle at that depth.

The south abutment and contiguous pillar were also successfully founded, according to the original intentions; but at the second pier from the south, the water being much deeper (being in the main channel, and the gravel bottom clean washed, like the second from the north) Mr. Smeaton judged it in vain to attempt any more pillars by coffer dams, because it would be an useless expense to construct a coffer dam without the least probability of mastering the water.

Early in the summer of 1778, the remaining five pillars were begun to be executed by caissons, and Mr. Smeaton attended the execution of the first that was laid, which was the fourth pier from the north side of the center arch; and which was done with so much expedition, ease, and convenience, that the season and weather turning out remarkable fine, the whole body of agents and workmen pressed forward to get as many of

of them done as possible while that favourable season lasted; but a number of blocks of a girdle course not immediately arising out of the quarries of a sufficient size for purpose, about the latter end of July four out of the five caisson piers were grounded upon the bottom of the river, and brought above water, when only one of them had any of the girdle stones brought and deposited, and this only in part around it; beginning from the western or up stream salient point, and extending from thence about half way round the pier on each side: in this state of things, after a remarkably dry season of some months, there came a violent rapid flood, not indeed a very high one, but the river being previously empty of water, and the rain which occasioned it falling very suddenly, it came down (being also urged by a violent wind at west) with uncommon rapidity; the consequence of which was that the four caisson piers, totally unguarded except as above-mentioned, were all washed at the west end, to the depth of about 15 inches at a medium, at the borders, and some to a greater breadth and some less; but the pier that had the half girdle course round the west point having been found to suffer along with the rest, though not in so great a degree, this induced Mr. Smeaton to think of a mode of defence not merely terminating upon the upper crust of the gravel as the girdle stones (which this event shewed was not sufficient to resist the increased velocity of the current, when passing by a new object), but instead of the girdle stones, to go some depth into the gravel; which it appeared practicable to do, by driving a casing of plank piles to surround every caisson pier at the distance of three feet, which would also enable him safely to underpin the parts underwashed.

To this proposition (though attended with an addition of expense unthought of before, of between five and six hundred pounds) Mr. Donkin very readily consented on the part of Mr. Errington. This was therefore immediately put in hand before further proceedings were gone upon.

Hitherto I have been particular, as it seemed absolutely necessary to give an adequate idea of the natural difficulties attending this work, and what a very small portion of them were known before it was originally enterprised by Mr. Gott; how gradually they unfolded themselves in consequence of the steps that from time to time had been taken; and how very far all were from being aware of the whole, when the work was begun by Mr. Errington under the direction of Mr. Smeaton. Suffice it therefore to say, that the casing of the damaged piers, and the undersetting of three of them, was proceeded upon with the greatest alacrity, and completed that season; nor did any other adverse accident happen to the completion of the bridge.

He concluded therefore to build a bridge of nine arches instead of seven, that it might have more legs to stand upon, in consequence of the natural weakness of the stratum; and by way of security to the piers, before they could be properly and sufficiently surrounded by the proposed slope of rubble, as well as after, in case of any derangement to the rubble defence, a girdle of stones in blocks of a ton weight and upwards, was proposed to be let down, and surround the base of each pier, to be fitted to each other, and to the pier they surrounded, and to be cramped together.

Upon this idea of construction Mr. Smeaton formed his original estimate; and which, from the simple mode of it, could be executed for a very moderate sum of money, in proportion to the largeness of the river and extent of the work; and which, in consequence, was bargained for by Mr. Errington, and the work proceeded with accordingly.

The north land-breast and the adjoining pier were successfully built upon piles encased as proposed; and the gravel being there very sufficiently compact (so as to afford only a moderate quantity of water) Mr. Smeaton determined to try to go on as far as he could upon that principle, and therefore ordered the second pier from the north abutment to be tried with a coffer dam, to encavate and found like the first; but when the pit was sunk but two feet under the level of the water outside, and not much more than half as much under the natural bed of the river, the water boiled up between the interstices of the gravel stones, bringing sand along with it, that it required forty men continually at the pumps to keep it down; and it was not without the utmost difficulty that the pier was founded on that principle at that depth.

The south abutment and contiguous pillar were also successfully founded, according to the original intentions; but at the second pier from the south, the water being much deeper (being in the main channel, and the gravel bottom clean washed, like the second from the north) Mr. Smeaton judged it in vain to attempt any more pillars by coffer dams, because it would be an useless expense to construct a coffer dam without the least probability of mastering the water.

Early in the summer of 1778, the remaining five pillars were begun to be executed by caissons, and Mr. Smeaton attended the execution of the first that was laid, which was the fourth pier from the north side of the center arch; and which was done with so much expedition, ease, and convenience, that the season and weather turning out remarkable fine, the whole body of agents and workmen pressed forward to get as many

of

of them done as possible while that favourable season lasted; but a number of blocks of the girdle course not immediately arising out of the quarries of a sufficient size for purpose, about the latter end of July four out of the five caisson piers were grounded upon the bottom of the river, and brought above water, when only one of them had any of the girdle stones brought and deposited, and this only in part around it; beginning from the western or up stream salient point, and extending from thence about half way round the pier on each side: in this state of things, after a remarkably dry season of some months, there came a violent rapid flood, not indeed a very high one, but the river being previously empty of water, and the rain which occasioned it falling very suddenly, it came down (being also urged by a violent wind at west) with uncommon rapidity; the consequence of which was that the four caisson piers, totally unguarded except as above-mentioned, were all washed at the west end, to the depth of about 15 inches at a medium, at the borders, and some to a greater breadth and some less; but the pier that had the half girdle course round the west point having been found to suffer along with the rest, though not in so great a degree, this induced Mr. Smeaton to think of a mode of defence not merely terminating upon the upper crust of the gravel as the girdle stones (which this event shewed was not sufficient to resist the increased velocity of the current, when passing by a new object), but instead of the girdle stones, to go some depth into the gravel; which it appeared practicable to do, by driving a casing of plank piles to surround every caisson pier at the distance of three feet, which would also enable him safely to underpin the parts underwashed.

To this proposition (though attended with an addition of expense unthought of before, of between five and six hundred pounds) Mr. Donkin very readily consented on the part of Mr. Errington. This was therefore immediately put in hand before further proceedings were gone upon.

Hitherto I have been particular, as it seemed absolutely necessary to give an adequate idea of the natural difficulties attending this work, and what a very small portion of them were known before it was originally enterprised by Mr. Gott; how gradually they unfolded themselves in consequence of the steps that from time to time had been taken; and how very far all were from being aware of the whole, when the work was begun by Mr. Errington under the direction of Mr. Smeaton. Suffice it therefore to say, that the casing of the damaged piers, and the undersetting of three of them, was proceeded upon with the greatest alacrity, and completed that season; nor did any other adverse accident happen to the completion of the bridge.

It may be proper to mention that when the first casing was completed, which was about the fifth pier from the north side, Mr. Smeaton ordered a trial to be made to pump out the water, which, if practicable, would have afforded the most easy way of under-setting the under-washed parts; but this being attempted, Mr. Pickernell reported, that with four double pumps and two single ones they had not been able to sink the surface of the water within the case above an inch below the surface on the outside. In this method, however, the coffer-dam cases used at Perth Bridge were driven so as to keep the water out of the foundation pits, when the surface of the river (when the tide was in) was from six to seven feet deep upon the bed of the river, and consequently against the sides of the casing. It would therefore have seemed that there had been some very palpable defect in driving these cases, had not the operations at the second pier from the north side sufficiently shewn how extremely open the bed of gravel is to the passage of water, and how impracticable every method was likely to prove that depended upon the drainage of the water, for the piers to be placed in the main channel of the river.

Several very rapid and much larger floods than that which did the mischief happened in the course of the succeeding winter, particularly one upon the 12th of December, when the water was within nine inches of the top of the inpost; when Mr. Pickernell marked a fall of two feet three inches, but without any material damage to any thing, which naturally induced all those concerned to proceed in the way they were then going on.

The season of 1779 was begun by new founding the western half of the pier, that the weather prevented from being completed the year before, which was the fifth from the north, and was done without caisson or draining the water, by means of an air chest or diving machine, that had been very successfully and conveniently employed in under-setting the other five damaged piers; and the pier before unbegun (being the sixth from the north) was the next in course founded by caisson; but with this difference, that the case was first drove all except the down stream salient pointing, before the caisson was floated into its place through this opening.

It would cause too great a prolixity to describe the particular operations of what followed the disaster of August 1778; nor can they be done without reference to figures; I shall therefore proceed to say that in the beginning of the year 1779, and also afterwards while the arches were throwing, the whole of the cases were guarded all round by a deposition of rubble; and to render it the more effectual against the torrents that this river then appeared subject to, the up stream points of the rubble bulwarks were extended to the length of 30 feet above the salient point of the cases respectively.

That

That the under-setting of the three piers so treated, was done so as to be as solid and effectual as the gravel stratum which the whole stood upon, as also the new founding of half of the fifth pier, and the original founding of the sixth, which was the last founded; and that the whole stood upon one bottom equally capable of supporting the weight of the superstructure built upon it, appears from this, that in the whole of the masonry, from the time of the accident in 1778 to the time of its total overthrow in the year 1782, there never appeared the least crack or set in any part of the work, not even in the parapets, which to those who are well experienced in bridge-building, will appear a remarkable instance of the soundness of the work; and furthermore, that the whole was sufficiently guarded against every accident that could be foreseen or expected appears from this; that in the year 1779 a remarkably rapid flood happened: which Mr. Pickernell observed, from marks upon the bridge, above and below, shewed a fall of three feet nine inches, occasioning a velocity of above 900 feet per minute, which not only passed without any material derangement; but, on the contrary, such changes as had been made in the bed of the river had been for the better, as it had acquired a more equal depth from side to side; the shallow parts becoming deeper, and even the deeper parts, by the depositing of gravel, had become shallower, and every flood that happened after, occasioned reports of the same kind till the last. In this manner, and with these ideas, every thing was satisfactorily finished, and the rubbing completed, according to Mr. Smeaton's directions, at or about Christmas 1780; and in the beginning of January 1781, Mr. Smeaton viewed the whole, in the presence of the magistrates of the county, who attended for that purpose, and found every thing done to his great satisfaction as well as theirs; and as such reported it to the county, as being completed according to Mr. Errington's agreement.

After all succeeding floods, every account was of the most flattering kind; so that previously to the last flood, every person concerned therein or therewith seemed perfectly easy as to the security of Hexham Bridge.

On Sunday evening the 10th of March 1782, there happened in that country a great downfall of snow, so great as to be a foot thick upon the plain ground; which was immediately succeeded by a violent hurricane: and as the nature of snow is to drink up the rain like a sponge, till it becomes perfectly saturated with water, it then bursts at once like a snow-ball in the fire, and may be fitly compared to an immense reservoir, extending over the whole country, and breaking loose altogether; and as the hills, and whole face of this country, are steep, comparatively like the roof of a house, the water is capable of coming down very suddenly; it then meets altogether, by the junction of the two Tynes, a little above Hexham, without having any considerable flat ground to spread itself upon. The next morning,

viz.

viz. Monday, March 11th, Mr. Donkin perceiving an extraordinary high flood in the river (which runs from west to east) attended with a very high westerly wind, he went down to the bridge, to observe the effects of the water upon it; but without the possibility of any damage happening thereto; when he observed, that the water was up to the top of the dooming (as there called), that is, the tops of the caps of the salient points upon the piers of the up stream side of the bridge, when it scarcely touched the down stream side, which makes a difference in level in passing the bridge of no less than between four and five feet, and which, according to the known rules of hydraulicks, will occasion a velocity of one thousand feet in a minute; but yet he was so far from apprehending any danger to the bridge, that he had just sent his son over it, to the south end, with two or three masons, to examine the state of the land-arches there, who reported all safe, but they had not returned above five minutes, before he began to observe symptoms of failure, when to his great surprize, "he perceived some particles of lime fall from the fourth arch, about the size of chaff, and the lime coming from thence and no where else, he pointed his observations to that part only. That the falling of the lime continued to encrease in size and quantity, for the space of a minute; that soon after he observed a crack across the bend of the arch towards the upper side of the bridge, which crack gradually widened, and in about a minute more, the splinters from the stones in the plain part of the spandrel, between the third and fourth arch, which he could perceive shake, gave way, and the two arches and a pier fell together; that the whole bridge was destroyed in half an hour," only two arches remaining whole, and one fell in part in the evening. Such was the sudden catastrophe of this much commended unfortunate bridge.

The second question is, Whether Mr. Errington was sparing of any thing necessary to give success to that mode of building, which Mr. Smeaton had adopted?

To this Mr. Smeaton can only bear his testimony, that he was not; nor did he ever hear him find fault with any expense, thought necessary by Mr. Smeaton; on the contrary, he always expressed his wishes to have the bridge completed in the most substantial and effectual manner. Nor did he ever appear disquieted by the disaster of 1778, or at the expense of what Mr. Smeaton had proposed as a necessary addition, though at so considerable an increase as five or six hundred pounds, as has been already stated.

Thirdly, respecting Mr. Pickernell, whether he did to the best of his power and knowledge, execute to a reasonable and possible extent, what was directed by Mr. Smeaton? And to this Mr. Smeaton thinks it but just to say as a witness, that he always looked on Mr. Pickernell throughout the whole proceeding, as a person particularly attentive

execute

execute orders and directions given by him, and upon whose capacity for that purpose, he could safely rely, after having shewn him the mode of going about any new operation, and upon whose reports of these operations, he could also safely rely; and the general workmanship of the bridge has been applauded by many, and discommended by none, it seems there is only one point in which Mr. Pickernell's execution of Mr. Smeaton's orders can be called in question, and that is respecting the driving down of the cales of piles, round the caisson piers, to a proper depth; it is therefore necessary to state this matter particularly.

Mr. Smeaton's written instructions were as follow; "The length of the piles should conform to the depth of the water; I would not wish the sheeting piles round the west end, and the first bay of the return on each side, to go into the ground more than about ten feet, and if they do not drive kindly, must be contented with less; from thence, each bay may be gradually less depth into the ground, so that round the down stream pointing seven feet will be sufficient. If the gage piles drive kindly, they may be longer by eighteen inches or two feet than the sheeting, but if not, they need not be above one foot longer."

To the above, in the course of the work, Mr. Pickernell reported, that having driven the piles of the fifth pier from the north, which was the first to which the casing was applied, the gage piles went down very well and entered two or three inches at a stroke, but when he came to drive the plank piles, they could not be got into the ground more than from five to seven feet.

He further reported in the course of this business, in regard to the sheet piling of the seventh pier from the north (or second from the south side) which was the last casing driven of the four damaged piers; that the bed of the river at the south side, is entirely full of large flat stones, such as they got out of Oakwood bank quarry, which have been the ruins of the boats' landings, taken away by floods and ice from time to time, and those stones had obstructed their sheet piling round that foundation, and had occasioned many of them to go out of their places at bottom, so that sundry cavities were occasioned thereby, more than in the last.

These were the representations of Mr. Pickernell, concerning his execution of Mr. Smeaton's orders, respecting the piling; so that if they were driven to a less depth, or in any manner less effectual than as above represented, Mr. Pickernell must answer to it, as Mr. Smeaton was totally unacquainted therewith, nor was any insufficiency in this part of

the

the work ever suggested to him by any person whatsoever during the course of the work, or since, till he heard of an opposition to Mr. Errington's bill for relie obligation.

But whether in reality Mr. Pickernell did this part of the work equal to the above representation of it or not, that the rising or falling of the bridge may not be wholly left to rest at Mr. Pickernell's disposal. Smeaton, in justice to Mr. Pickernell as well as himself, thinks it necessary to declare, that for the reasons already assigned, (as well as the verification thereof during the course of the work, by every flood that happened) so great and absolute was his dependence upon the application of Oakwood bank quarry rubble, as an ultimate defence to controvert the force of the Tyne's floods (no part of it laid round the coffer dam foundations, having been moved); that provided the piles of the casings were but driven into the ground, so far as to fix fast therein, and so close together, that though the cases might not hold water, they might retain the gravel from being washed out through the chinks from under the piers; he had not the least doubt of preventing any material damage ever being done to the pile work, by the application of the said rubble to surround them. This sentiment, however, though it dictated that part of his instructions, "get the bays of sheet-piling at the west end of the piers down to ten feet if you can, if you cannot, we must be contented with less;" and also made Mr. Smeaton contented with what was above reported to him, as the most imperfect part of the performance; yet he never communicated this opinion to Mr. Pickernell, or any other person; lest the workmen from hearing thereof, might be induced to satisfy themselves with doing less than otherwise they might be capable of, in the way of getting them down as far as they could.

Whether Mr. Smeaton's opinion, concerning the security of Oakwood bank quarry rubble, was well or ill-founded, will be further examined in the sequel; but this is certain, that the driving of the cases not being completed before the middle of September, and being then very desirous to take advantage of the security they afforded, to get the piers underfet, if possible, or otherwise secured before the heavy winter floods came on, he concluded, that if the experience of these floods should shew a need of greater strength and defence, it might be added in the course of the next season.

This autumn of 1778, in reality, afforded the experience of a considerable number of floods, amongst which, the last, which was of December 12, was a capital one, and the highest that had been since the great inundation of 1771; and the water on the west or up stream side of the bridge, was within nine inches of the top of the impost of the second pier.

pier from the north, when at the east end it was one foot three inches below it, so that the water was then no less than two feet three inches, and which would produce a velocity of seven hundred feet per minute.

After the water was subsided so as to afford a full examination, Mr. Pickernell reported the effect; viz. that there were but very few of the rubble stones removed from where they were thrown in round the foundation. What were moved, were from the west shoulders; but that from the third pier to the north, round which no stones had been deposited, it had torn up the gravel from the salient point and west shoulders, to the depth of three feet; and that from thence to the stones that were laid round the second pier, it had deepened the bed of the river seven inches, (which before was too shallow); but as to all the other part of the bridge he could not perceive it altered in the least.

The experience therefore of these floods, and particularly that of the 12th December, all concurred in proving, that the Oakwood bank quarry rubble was a sufficient defence against every violence of the Tyne: so that it did not appear necessary to introduce any new mode of defence, but only to apply the rubble in the most effectual manner; and as the west shoulders appeared to be the parts that the greatest stress came upon, Mr. Smeaton ordered that the water might not meet with so sudden an opposition there, but be more evenly, slopingly, and gradually brought thereupon, that the west salient points of the rubble should be extended westward of the salient points of the cases respectively, to the length of at least thirty feet; which was accordingly executed by Mr. Pickernell upon all the caisson piers.

4thly, We come now to the fourth and last question, viz. Whether under all the experience and knowledge of the subject as it now stands, the present bridge should be attempted to be reinstated, or a new one built at Hexham?

This question is indeed of far the most material import; for it is of little consequence to the public, in the present state of things, whether Mr. Smeaton misjudged of the subject? Whether he was deceived himself, or was deceived by others? Or, whether Mr. Pickernell did or did not do his best, towards a full execution of Mr. Smeaton's orders, in regard to the driving the casing piles? Nor is it of any consequence to know, that in point of art, but without any regard to, or limitation of expense, a bridge is possible to be built: the true question is, Is it fitting for the county to undertake it? Supposing the Treasurer in possession of whatever sum can be recovered from Mr. Errington, in consequence of his obligation, will it not (like Sir Walter Blackett's three thousand pounds)

the work ever suggested to him by any person whatsoever during the course of the work, or since, till he heard of an opposition to Mr. Errington's bill for relief obligation.

But whether in reality Mr. Pickernell did this part of the work equal to the above representation of it or not, that the rising or falling of the bridge may not be wholly left to rest at Mr. Pickernell's disposal. Smeaton, in justice to Mr. Pickernell as well as himself, thinks it necessary to declare, that for the reasons already assigned, (as well as the verification thereof during the course of the work, by every flood that happened) so great and absolute was his dependence upon the application of Oakwood bank quarry rubble, as an ultimate defence to contravene the force of the Tyne's floods (no part of it laid round the coffer dam foundations, having been moved); that provided the piles of the casings were but driven into the ground, so far as to fix fast therein, and so close together, that though the cases might not hold water, they might retain the gravel from being washed out through the chinks from under the piers; he had not the least doubt of preventing any material damage ever being done to the pile work, by the application of the said rubble to surround them. This sentiment, however, though it dictated that part of his instructions, "get the bays of sheet-piling at the west end of the piers down to ten feet if you can, if you cannot, we must be contented with less;" and also made Mr. Smeaton contented with what was above reported to him, as the most imperfect part of the performance; yet he never communicated this opinion to Mr. Pickernell, or any other person; lest the workmen from hearing thereof, might be induced to satisfy themselves with doing less than otherwise they might be capable of, in the way of getting them down as far as they could.

Whether Mr. Smeaton's opinion, concerning the security of Oakwood bank quarry rubble, was well or ill-founded, will be further examined in the sequel; but this is certain, that the driving of the cases not being completed before the middle of September, and being then very desirous to take advantage of the security they afforded, to get the piers underfet, if possible, or otherwise secured before the heavy winter floods came on, he concluded, that if the experience of these floods should shew a need of greater strength and defence, it might be added in the course of the next season.

This autumn of 1778, in reality, afforded the experience of a considerable number of floods, amongst which, the last, which was of December 12, was a capital one, and the highest that had been since the great inundation of 1771; and the water on the west or up stream side of the bridge, was within nine inches of the top of the impost of the second pier

pier from the north, when at the east end it was one foot three inches below it, so that the water was then no less than two feet three inches, and which would produce a velocity of seven hundred feet per minute.

After the water was subsided so as to afford a full examination, Mr. Pickernell reported the effect; viz. that there were but very few of the rubble stones removed from where they were thrown in round the foundation what were moved, were from the west shoulders; but that from the third pier to the north, round which no stones had been deposited, it had torn up the gravel from the salient point and west shoulders, to the depth of three feet; and that from thence to the stones that were laid round the second pier, it had deepened the bed of the river seven inches, (which before was too shallow); but as to all the other part of the bridge he could not perceive it altered in the least.

The experience therefore of these floods, and particularly that of the 12th December, all concurred in proving, that the Oakwood bank quarry rubble was a sufficient defence against every violence of the Tyne: so that it did not appear necessary to introduce any new mode of defence, but only to apply the rubble in the most effectual manner; and as the west shoulders appeared to be the parts that the greatest stress came upon, Mr. Smeaton ordered that the water might not meet with so sudden an opposition there, but be more evenly, slopingly, and gradually brought thereupon, that the west salient points of the rubble should be extended westward of the salient points of the cases respectively, to the length of at least thirty feet; which was accordingly executed by Mr. Pickernell upon all the caisson piers.

4thly, We come now to the fourth and last question, viz. Whether under all the experience and knowledge of the subject as it now stands, the present bridge should be attempted to be reinstated, or a new one built at Hexham?

This question is indeed of far the most material import; for it is of little consequence to the public, in the present state of things, whether Mr. Smeaton misjudged of the subject? Whether he was deceived himself, or was deceived by others? Or, whether Mr. Pickernell did or did not do his best, towards a full execution of Mr. Smeaton's orders, in regard to the driving the casing piles? Nor is it of any consequence to know, that in point of art, but without any regard to, or limitation of expense, a bridge is possible to be built: the true question is, Is it fitting for the county to undertake it? Supposing the Treasurer in possession of whatever sum can be recovered from Mr. Errington, in consequence of his obligation, will it not (like Sir Walter Blackett's three thousand pounds)

pounds) be a temptation to the county to spend still much larger sums upon an unfruitful project; and it may reasonably be supposed, that the whole county stock is not an unlimited sum; nor can it be properly expended in the erection of a bridge at one single passage.

It is now known for a certainty, what was not, and could not have been known before the erection of this bridge, that there is a possibility of natural causes being so combined, as to produce a flood so large, and of so sudden a nature, as to produce a velocity of the water exceeding one thousand feet in a minute; and whether even this may, or may not, be the uttermost limit of Nature, is not in the power of any man to calculate:—

That the velocity of seven hundred and twenty feet per minute, arising from a difference of two feet three inches, as per flood of December 1778, was sufficient to tear up and remove the natural bed of gravel, which forms the bed of the river in this place, wherever there was a particular set upon it, but was not capable of moving or materially deranging the defences composed of Oakwood quarry rubble.

That the velocity of nine hundred and thirty feet, resulting from a difference of three feet nine inches, in a flood of the 1st of December 1779, still made not the least alteration in the defences, nor to any part of the bed of the river, save that the rubble stones deposited at the third pier where the current had torn up the natural gravel in the flood of December 1778, were now wrecked full and covered with gravel, and reduced to the level of the adjacent parts. Another flood succeeded this in the compass of ten days, that rose within eight inches as high as the former, but in this nothing happened of any kind; in short, the bridge being now erected, as far as it was concerned with the water, all the arches cleared, and the defences completed, after a considerable number of great floods, and nothing happening in consequence, every one seemed so entirely satisfied of the stability of the bridge, that even the Gilligate people, Mr. Pickernell observed, ceased their visits; who before had constantly, after every flood, come to inspect, in hopes of finding something correspondent to their prayers and wishes for the downfall of the bridge.

Mr. Smeaton was, however, agreeably surpris'd on having this account, that the fall of water had been so great, and no harm ensued; for had it been possible for him to be apprised of such a fall before hand, he never should have recommended to Mr. Errington to have undertaken to erect a bridge upon that bed of gravel.

It therefore at this time appears plain, that though the Oakwood bank rubble will resist a velocity of the water of nine hundred and thirty feet in a minute, yet it is capable of being all removed and carried away by the velocity of the water of, or a little exceeding, one thousand feet per minute; a velocity resulting from a difference of forty-four, as it was or upwards in the flood of March 1782; and that the gravel bed itself is capable of being torn up by a much less degree of velocity; the question then is, How in such situation a foundation can be laid and effectually secured?

Shall we attempt to build a wall across the bottom of the river, according to Mr. Wooler's proposition? Experience has shewn in the building of the last bridge, that the gravel is of so open a nature in the main channel of the river, that it is impracticable to drain off the water. Mr. Smeaton is not to put limits to the invention and ingenuity of men; but neither his observation, experience, nor invention, has hitherto suggested any effectual method of founding such a wall, without draining off the water; and the same will apply to the penning the bottom across the river.

But for a moment, suppose the thing done: this wall or this apron, must have a termination; and wherever it terminates, experience shews, a rapid current will form a deep hole, to twenty, or even thirty feet depth, and upwards; and if the gravel under the foundation gets loose, the downfall of the whole is the consequence.

2dly, Suppose we attempt to build it in an excavation upon piles encased, as was done at Perth, the same difficulty arises; we cannot get out the water; and if done, as rubble will not lie to defend it, the gravel bed being scooped out, beyond all practicability of driving piles, the piers being sapped, the same unfortunate circumstance must ensue.

3dly, Suppose we attempt it by excavation with ballast lighters, and drive down piles even with the bottom of the excavation pits, to found the piers upon; which may doubtless be done, without taking off, or drainage of the water; still, if neither the bed of gravel itself, nor quarry rubble, is capable of resisting the violence of the current, when the gravel bed is destroyed or deranged, so that the piles are laid bare, the pillars will be sapped, and destruction equally ensue: nay, even suppose the piles could be encased without taking off the water, yet this is only giving the river a little more work to do; for if rubble is carried away, as we find it must be, it is no defence; and we do not know the depth to which the gravel can be scooped out and excavated by the violence of this river; the

the foundations therefore, however deep, can be ultimately sapp'd, and the same ruin ensue.

In short, turn ourselves which way we will, nothing seems certain in this business, but a very great expense, how commensurate with the county's funds, must be left to those to judge of who know them: but this Mr. Smeaton will take upon himself to say, that he sees no way of making foundations for a bridge to stand upon, for the whole sum in which Mr. Errington stands obligated to the county, that is likely to be attended with any certainty of permanency, much less also to build a bridge upon those foundations, for the same sum.

THE following is a Copy of a Paper delivered at Northumberland Assizes 1783, by Henry Errington, Esq., to Gawen Aynsley, Esq., Chairman for the County of Northumberland, but which appears to have been originally intended to be delivered to the Grand Jury, which had been previously discharged, as the Words Gentlemen and Magistrates, in the Original, are substituted for Grand Jury.

MR. ERRINGTON'S contract with the Justices of the Peace respecting Hexham Bridge having placed him in a very disagreeable situation, he, as well on his own account as on the part of the County, wishes the Gentlemen and Magistrates, now assembled, as a respectable body of the County, would be pleased to take the following short statement of facts into their consideration.

Mr. Errington undertook to build the bridge according to a specific plan, under the direction of Mr. Smeaton, and to uphold, support, repair, maintain, rebuild, and keep it in good and sufficient repair for the term of seven years, to be computed from the time it should be certified under the hands of two justices to be so built.

The bridge being completely finished according to such plan and direction, was in January 1781, certified for.

The

The plan to which Mr. Errington was confined, was not only a plan of the superstructure, but also of the foundation, and of the manner in which such foundation was to be laid.

In March 1782, the bridge was thrown down, from which circumstance it is evident, that to rebuild it according to the same plan would be ineffectual, and from the nature of the contract, it is not in the power of the contracting parties to alter or vary it; indeed, Mr. Smeaton, whose direction Mr. Errington was bound to obey, has declared that it is not in his power to devise a better. If therefore the County should insist on Mr. Errington's rebuilding the bridge, a great portion of the seven years would expire before he could complete it; (two years and a half having already elapsed since the certificate)—and if by favourable seasons it should be capable of being upheld till the end of the seven years, he would then be discharged from his obligation, and the burthen would fall upon the County; Mr. Errington in common with the land owners of the county in general, and by having an estate in the vicinity of Hexham in particular, feels himself interested in having a bridge built, which by an alteration in the mode of structure may be attended with a probability of being permanent, and he has been informed that other engineers lately consulted by the Justices are of opinion that it is practicable; he, therefore, conceives that it would be more advantageous to the County to accept from him such sum of money as shall be estimated equal to the expense of repairing the bridge, and putting the same into such a situation as his contract requires, and apply such sum together* with the materials, (which are of more than four times the value of those received by Mr. Errington from the County), towards building a new bridge according to some other plan, than to require him to repair the old one upon the former erroneous principles. — And if the Gentlemen and Magistrates should be of the same opinion, Mr. Errington doubts not the Justices will, as trustees for the public, readily adopt what shall so appear to be the sense of the County.

* Value of materials received by Mr. Errington from the County, and acknowledged by him	£
to be estimated at	3000
Which multiplied by 4	12,000

Which is 2900l. more than the penalty of Mr. Errington's bond to the County, and many thousands more than expended.

Mr. MYLNE's Second Report.

Edinburgh, 30th September 1783.

To the Magistrates and Justices of Peace for the County of Northumberland,
&c. &c.

Gentlemen,

A PAPER has been transmitted to me by Mr. Davidson, Clerk of the Peace, which contains a proposition from Mr. Errington to pay a certain sum (to be fixed hereafter) in lieu of rebuilding Hexham Bridge; and he requests me, by directions of Mr. Aynsley, the Chairman, to send my full sentiments thereon, to be read before your meeting of the 8th October next.

As it will be convenient for me to attend you at the said meeting, I apprehend it is not necessary to say much on this occasion; other than stating a few words on some matters of fact, which require to be ascertained, before any one can judge with certainty and precision. Another reason requires me to be the more concise at present, as in the event of not agreeing with Mr. Errington, and the subject being discussed at law, every previous animadversion would in that event be ill timed and premature.

The ground work of the proposal, and the propriety of the reasoning which it contains, depend upon the following matters:

1st, It states that the agreement was to build according to a specific plan.

2dly, To do that under the direction of Mr. Smeaton.

3dly, That it was completely finished according to such plan, and under such direction. And

Lastly, That he was confined to such specific plan; which was not only a plan of the superstructure, but also of the foundation part; and of the manner in which such foundation was to be laid.

On the first head, it will appear, that all the foundations were, by the plan annexed to the articles of agreement, to have been laid full five feet below the water line, in masonry or timber framed work; and the two abutments, and the two piers next the abut-

ments,

ments, are proposed to be piled in such manner as shall appear necessary on opening the ground.

In all other respects whatsoever, either as to the quantity or quality of the piling under these parts so mentioned, and under any part of the other eight piers, or of any manner whatsoever of laying all or any of the foundations, the plan does not hold forth any specific manner of laying the foundation; but on the other hand, leaves all these particulars to the judgment and adoption of the contracting party.

On the second head, the agreement entered into on the proposals of Mr. Errington and his agents, was certainly to put the whole under the direction of Mr. Smeaton; and the act of parliament which followed thereupon, confirms it to a certainty not to be shaken. The reference thus to be held to the judgment of Mr. Smeaton, was in no points more evidently necessary than in the manner of laying the foundations, which were not specified at all, as well as in many other things impossible to be contained in drawings, written agreements, or in acts of parliament. But, in the unfortunate event of things, I conceive, the operation of Mr. Smeaton's directions in all matters not specified above mentioned, he was led astray, and that his directions were not followed. Proceedings which were easy in their nature, were followed up with a fatal rapidity, that laid the seeds of ruin; and the guard works, which were added, on after consideration, and the experience of the shallowness of the foundations, were not executed consistently with the correctness and good sense of his orders.

His directions I conceive to have been clear and sufficient if they had been fulfilled; his candour will not allow him to say thus much; a commendable regard to others engaged in the executive branch, suppresses what ought to be said: but I who feel for the character and reputation of so great an artist, and every man so peculiarly situate as he is, must be permitted to say, that the purport and effect of his directions were not executed, and of course, that he was deceived.

On the third head, it is necessary to state that the foundations were not laid according to the plan, so far as the specification thereof went. To begin at the north end, the buttment is not so deep as shewn by the drawing by two feet; the first pier by three feet five inches, the second pier by two feet four inches, the third pier by two feet eleven inches, the fourth pier by seven inches, the fifth pier was ten inches more in depth than the plan, the sixth pier was in like manner eleven inches, the seventh was also six inches, the eighth pier is two feet short of its depth; and the south buttment is two feet in like manner less than it ought to be.

From this statement, founded on the best evidence I could procure, the bridge was not built according to the design agreed on where it could have been; and that the directions given were not followed literally and effectively.

On the last head, I have sufficient shewn that the specification of the plan did not confine the bridge in manner of laying foundations, nor in the shape and extent of the works. Anything might have been done under the agreement, which a more intimate knowledge of the bed of the river, and the experience of the works themselves, gave, during the time of the execution: in fact, it is shewn, that the parts specified were altered and modified to suit the manner adopted for the execution.

The conclusion, therefore, naturally draws me to end with saying, that no argument can be reasonably built on the idea of being confined to a specific plan agreed for, or executed in those parts, to wit, the foundations, on which this question depends. And I am thoroughly convinced that if Mr. Smeaton, possessed as he is of so much strength of judgment and variety of resources, were to view the work and examine its present state, with a view to its repair, he could with satisfaction to himself undertake to reconstruct the bridge according to the agreement, with the same expectancy of permanent durability as he had at first setting off with this undertaking.

What remains to be said will come better into the discussion which is proposed to be held at your intended meeting; until which time, I remain,

Gentlemen,

Your very humble and much obliged servant,

ROBERT MYLNE.

OBSERVATIONS on Two Reports of Robert Mylne Esq. concerning Hexham Bridge, by J. SMEATON, Civil Engineer.

THERE are so many points contained in the two reports of Mr. Mylne, of the 24th April and the 30th September 1783, in which I entirely differ with that gentleman in opinion, that to make the proper observations upon the whole, would draw me out to a length that in the present state of things I would wish to avoid. I shall therefore content myself

myself with observing upon those that I look upon to be the foundation of that difference of opinion; and upon which the merits of the question seem principally to depend. I therefore pass over the compliments that Mr. Mylne's politeness prompts him to pay me on this occasion; and particularly as they seem to be at my own expense. For the greater ease of reference, I shall apply to the printed copy of Mr. Mylne's reports.

Mr. Mylne says, page 5th, (298 of this volume) "The existence of a sand below, and a supposed hardness and concretion of five feet, or any such measure of the upper parts, seem to have precipitately and fatally determined the plans of operation at first setting out; and appear to me to be equally the cause of the present precipitate opinion for abandoning the work as impracticable."

He also says, page 4, (298) "Mr. Smeaton, than whom there is no person or artist better instructed, more knowing, and of a more penetrating and correct judgment, must have been deceived in the collection of facts and materials, on which he established his plan of operations."

Now, if in the following detail it shall appear that Mr. Smeaton made a proper collection of facts whereon to judge; and did make a proper judgment thereon, so far as at the time he was to form this judgment had come to light; then, Mr. Mylne's reflections on this judgment must appear unfounded, and will in course fall to the ground.

Mr. Mylne acknowledges himself to have been made acquainted with the reasons and motives of Mr. Smeaton; for page 6th, (298) he says, "I have seen and examined all Mr. Smeaton's papers, I have heard all the particulars, and history of his proceedings and motives for the method of operations, which he adopted:" and Mr. Mylne knows that this intelligence was from Mr. Smeaton himself, before Mr. Mylne went down to examine the works and persons concerned, and employed in the detail of its execution: and that it was in this conference that Mr. Smeaton mentioned to him, that the ground and reason which influenced his judgment in not sinking the piers of the bridge deeper into the bed of the river was an established opinion that the greatest part of the river's bed consisted of a gravel, very hard compacted together and difficult to penetrate at its upper surface; but which diminishes in compactness from the surface downwards; so that at some depth exceeding five feet, it deviated into a sand, and ultimately into a quicksand or mud. The existence of such a sand below, as also a supposed hardness and concretion of five feet, or any such measure, of the upper parts, Mr. Mylne explodes in the terms already quoted: but as herein resides the foundation of that entire difference of opinion that still subsists

subsists betwixt Mr. Mylne and Mr. Smeaton, it seems proper now to examine the grounds whereon Mr. Smeaton established this opinion, and also the grounds whereon Mr. Mylne explodes it; because, if well founded, from what *appeared at the time*, it must be admitted sufficient in reason for Mr. Smeaton's determining his plan of operations according to it, though, since the fatal accident, any thing should appear to the contrary; and if on the other hand, from any thing that can be deduced from M. Mylne's operations, Mr. Smeaton's original conclusions stand uninvalidated; then it must appear, that Mr. Mylne must have been drawn into a precipitate opinion, or, as he terms it, *deceived*.

That Sir Walter Blackett built a bridge at Hexham, which not long after it was finished, was thrown down by the great flood in 1771, in one night, and the materials almost totally dispersed, is an event too notorious for Mr. Smeaton to be *deceived* in.

That the foundations of this bridge were let into the bed of the river, well founded upon a great number of piles, and a platform upon the heads of them 12 inches thick, of solid balks judiciously rabbetted together, Mr. Smeaton could not be *deceived* in; having been eye witness to many of the operations.

That all the piers, arches, and one of the two abutments were totally destroyed, and the whole length of one side of one of the platforms raised out of the water, half way between the horizontal line and the perpendicular; in this also Smeaton could not have been *deceived*, having seen it for several years together; and was exposed to the full view of every one that passed by.

From the above facts, Mr. Smeaton inferred, that though the upper crust was hard gravel, yet a much more soft and yielding material lay underneath it, otherwise the bottom, could not have been turned up in the manner mentioned, and that the foundations would have been more secure, had they been laid upon the upper crust without its being broken, by excavating or driving piles: and which is evidently proved by the subsequent operations that now come in course to be mentioned.

That after this accident Sir Walter Blackett, chusing rather to forfeit the penalty of the bond*, in which he was obliged to uphold the bridge for seven years, than to attempt it again, the magistrates of the county employed Mr. Wooler, then an eminent engineer, to begin another bridge near the same place: and that in consequence he built a land-

* Penalty 3000l.

breast on the north side; and many preparations being made, and every thing ready for pier, upon the same side; on digging the foundation put into the bed of the whole work was put a stop to for some reason or other; and in this Mr. Smeaton could not be deceived; because at that time he was often at Hexham, was well acquainted with Mr. Wooler, and saw the operations going on, and afterwards discontinued: and it will be further proved by living evidence, that reason for discontinuing the work, was the *softness* of the bottom of the foundation; and to ascertain whether this softness was particular to *that place*, a pit within the solid bank was dug upon the opposite side of the river, in the bottom of which the same soft stratum prevailed; and to this some of the magistrates were themselves witnesses, as will also be proved: it can also be proved from a letter of the said Mr. Wooler deceased, that in his opinion a *permanent bridge could not be established here*, by building a solid wall of six feet high, and 42 broad, quite across the river; which was observed was an expedient that has succeeded where *expense was not regarded*. He further says, "that the attempting to set a bridge upon such an enormous depth of quicksand, over a river so subject to floods as the Tyne, may be deemed so hazardous as to be next to imprudence itself."

Mr. Smeaton therefore could not be *deceived* as to the existence of a hard stratum of gravel at the top, with a quicksand under it, at either of the places just described*: as Mr. Wooler's operations fully prove what was the cause of the failure of the first bridge.

Mr. Jonathan Pickernell, who was brought from London to be employed in this business under Mr. Wooler, and recommended by him, will further prove, that he was employed to bore the river, which he did in various places, and verbally reported to Mr. Smeaton, that wherever he had tried the river he constantly found a quicksand to take place underneath the upper bed of gravel; and that he had reported the same to *the clerk of the peace*.

In this Pickernell might have deceived Mr. Smeaton; in his never having made such borings, nor made such report: but Smeaton did not rest it here; for in the very place where he built the bridge, he tried the bottom of the river, not by boring, but by driving down a pointed iron bar, in various places across the river, to the depth of nine or ten feet, and constantly found, that though the entry of the bar was in all places difficult, yet at every blow it went more and more easy; however at this depth the gravel felt so tolerably compact as

* N. B. The Dwarf wall, the place recommended by Mr. Mylne, is near the original bridge.

to be deemed by him sufficient for supporting a bridge, *provided* the upper crust was not broken by digging or piling; and provided, the weight upon each pier was not too great, which would be the consequence of wide arches; and as was the case with Sir Walter Blackett's bridge: the middle arch being 70 feet.

Now, if in the conclusion I drew from those trials of the river's bottom by the bar, I have been deceived; I deceived myself, as I was not beholden to the *patience and perseverance* of Mr. Pickernell only, for as I not only directed but assisted in the operation myself, I saw with my own eyes, and felt with my own hands.

These are the facts on which Mr. Smeaton built his plan of operations, which facts, if valid, he challenges Mr. Mylne to shew, that the methods he grounded them on, were not the most likely, *as far as was then known*, to produce a permanent bridge, that if, at all, must be erected at such a moderate expense as the county of Northumberland was likely to raise: for to build a solid wall across the river whereon to set it, he judged with Mr. Wooler to be improper, except where *expense was not to be regarded*.

Let us now see what Mr. Mylne has on the other hand established to invalidate these facts. He says, page 3d, (297) "I have bored the river at the bridge to the depth of 23 feet below the latter water level, in a place where I might not be led astray by any alteration formed by the said flood in its milder velocity; and I have found under the testimony and perseverance of Mr. Wake, that the soil and texture of the bed of the river at this place is uniformly a composition or congeries of roundish and flat stones, gravel and sand, of equal quality and consistence in the whole of that depth."

Mr. Mylne then caused a hole to be bored to the depth of 23 feet into a bed of gravel: but was this the only hole? Mr. Mylne makes no mention of any other. Where did he bore it? Mr. Mylne does not say; but contents himself with telling us, he did not bore it in a place where the gravel was liable to be disturbed by the impetuosity of the river. But does Mr. Mylne think this was sufficient to determine what the soil and texture of that part of the bed of the river was which *was liable* to be so disturbed? Mr. Mylne says, page 4th, (297) that the bed of the river "though hard to the touch of boring, and compact to the eye, and feeling of instruments, is wonderfully loose, and unconnected in its parts, *inasmuch* that the bed of the river Tyne seems to shift and alter its form, extent, and situation with every flood more or less; and tearing up at one time to a great depth that fair moulded and well-laid hollow, which the stream had laid for itself

" upon

" upon some former occasion." This was not the part, therefore, that Mr. Mylne chose to examine otherwise than in his mind's eye; he chose a place not so liable to alter, although the greatest part of the bridge, and particularly that part that first gave way, was founded, and obliged to be founded, upon *this fair moulded and well laid hollow*, which the stream had laid for itself upon some former occasion. Now Mr. Smeaton cannot be deceived in this, that it was in this very part where he drove down his bar: it was in the deepest part of the river; and all his trials were made in a boat, though the river was then in its low state. Whereas it will be proved in evidence, that the part where Mr. Wake bored was upon a dry gravel bed, nearly abreast of the place where Mr. Smeaton put down his second coffer dam pier: and where the foundation was actually sunk into the bed of the river, as deep as it possibly could be for water*; in confidence that the gravel bed there was quite as deep as Mr. Wake's boring has since proved it to be. The fact was, that Mr. Smeaton's original plan and proposition was to build the land-breast and one pier, on each side, with coffer dams, sinking the foundation thereof into the bed of gravel, piling underneath and round these works, to as great a depth as should appear necessary on opening the ground; and which accordingly were done: but finding, on founding the north land-breast, and also the north pier, that the gravel bed extended still further into the bed of the river than was at first expected, he directed the second pier (opposite which Mr. Wake bored), to be laid in the same way; leaving then only five of the eight piers to be built in the *fair moulded hollow* to be subject to the *vast powers* of the *floods* of this river; and this he was under a necessity of doing, as he found it impracticable to drain off the water so as properly to establish the piers upon a foundation of piling: judging it, therefore, the safest expedient to preserve the upper surface whole, which he found by far the hardest, and to found the rest of the piers by caissons upon the bottom of the river, defending the basis thereof by such outworks as then were in contemplation.

How, therefore, it happens that because at the place where Mr. Wake bored "the soil and texture of the bed of the river is uniformly a composition or congeries of roundish and flat stones, gravel, and sand, of equal quality and consistency throughout the whole of that depth;" it is and must be so everywhere else, as well where he did not bore, as where he did! or how Mr. Mylne becomes entitled to report that Mr. Smeaton's investigation of a sand (or soft matter) below, and a greater hardness or concretion of the matter above, as appeared to Mr. Smeaton, from driving the bar as already described, is an unfounded idea, Mr. Smeaton cannot see to arise otherwise

* It rose so plentifully from the bottom as to employ near 40 men at the pumps.

to be deemed by him sufficient for supporting a bridge, *provided* the upper crust was not broken by digging or piling; and provided, the weight upon each pier was not *too great*, which would be the consequence of *wide arches*; and as was the case with Sir Walter Blackett's bridge: the middle arch being 70 feet.

Now, if in the conclusion I drew from those trials of the river's bottom by the bar, I have been deceived; I deceived *myself*, as I was not beholden to the *patience and perseverance* of Mr. Pickernell only, for as I not only directed but assisted in the operation myself, I saw with my *own eyes*, and felt with my *own hands*.

These are the facts on which Mr. Smeaton built his plan of operations, which facts, if valid, he challenges Mr. Mylne to shew, that the methods he grounded them on, were not the most likely, *as far as was then known*, to produce a permanent bridge, that if, at all, must be erected at such a moderate expense as the county of Northumberland was likely to raise: for to build a solid wall across the river whereon to set it, he judged with Mr. Wooler to be improper, except where *expense was not to be regarded*.

Let us now see what Mr. Mylne has on the other hand established to invalidate these facts. He says, page 3d, (297) "I have bored the river at the bridge to the depth of 23 feet below the latter water level, in a place where I might not be led astray by any alteration formed by the said flood in its milder velocity; and I have found under the testimony and perseverance of Mr. Wake, that the soil and texture of the bed of the river at this place is uniformly a composition or congeries of roundish and flat stones, gravel and sand, of equal quality and consistence in the whole of that depth."

Mr. Mylne then caused a hole to be bored to the depth of 23 feet into a bed of gravel: but was this the only hole? Mr. Mylne makes no mention of any other. Where did he bore it? Mr. Mylne does not say; but contents himself with telling us, he did not bore it in a place where the gravel was liable to be disturbed by the impetuosity of the river. But does Mr. Mylne think this was sufficient to determine what the soil and texture of that part of the bed of the river was which *was liable* to be so disturbed? Mr. Mylne says, page 4th, (297) that the bed of the river "though hard to the touch of boring, and compact to the eye, and feeling of instruments, is wonderfully loose, and unconnected in its parts, *inasmuch* that the bed of the river Tyne seems to shift and alter its form, extent, and situation with every flood more or less; and tearing up at one time to a great depth that fair moulded and well-laid hollow, which the stream had laid for itself

" upon

" upon some former occasion." This was not the part, therefore, that Mr. Mylne chose to examine otherwise than in his mind's eye; he chose a place not so liable to alter, although the greatest part of the bridge, and particularly that part that first gave way, was founded, and obliged to be founded, upon *this fair moulded and well laid hollow*, which the stream had *laid for itself upon some former occasion*. Now Mr. Smeaton cannot be deceived in this, that it was in this very part where he drove down his bar: it was in the deepest part of the river; and all his trials were made in a *boat*, though the river was then in its low state. Whereas it will be proved in evidence, that the part where Mr. Wake bored was upon a dry gravel bed, nearly abreast of the place where Mr. Smeaton put down his second coffer dam pier: and where the foundation was actually sunk into the bed of the river, as deep as it possibly could be for water*; in confidence that the gravel bed there was quite as deep as Mr. Wake's boring has since proved it to be. The fact was, that Mr. Smeaton's original *plan* and proposition was to build the land-breast and one pier, on each side, with coffer dams, sinking the foundation thereof into the bed of gravel, piling underneath and round these works, to as great a depth as should appear necessary on opening the ground; and which accordingly were done: but finding, on founding the north land-breast, and also the north pier, that the gravel bed extended still further into the bed of the river than was at first expected, he directed the second pier (opposite which Mr. Wake bored), to be laid in the same way; leaving then only five of the eight piers to be built in the *fair moulded hollow* to be subject to the *vast powers* of the *floods* of this river; and this he was under a necessity of doing, as he found it impracticable to drain off the water so as properly to establish the piers upon a foundation of piling: judging it, therefore, the safest expedient to preserve the upper surface whole, which he found by far the hardest, and to found the rest of the piers by caissons upon the bottom of the river, defending the basis thereof by such outworks as then were in contemplation.

How, therefore, it happens that because at the place where Mr. Wake bored "the soil and texture of the bed of the river is uniformly a composition or congeries of roundish and flat stones, gravel, and sand, of equal quality and consistency throughout the whole of that depth;" it is and must be so everywhere else, as well where he did *not* bore, as where he did! or how Mr. Mylne becomes entitled to report that Mr. Smeaton's investigation of a sand (or soft matter) below, and a greater hardness or concretion of the matter above, as appeared to Mr. Smeaton, from driving the bar as already described, is an unfounded idea, Mr. Smeaton cannot see to arise otherwise

* It rose so plentifully from the bottom as to employ near 40 men at the pumps.

than from an intuitive knowledge in Mr. Mylne that Mr. Smeaton does not pretend to: inasmuch as that Mr. Mylne does not adduce the trial of any experiment from whence that inference can fairly be made.

Mr. Smeaton, therefore, refers it to any impartial person who shall peruse Mr. Mylne's reports referred to, and these observations upon them, whether it is Mr. Smeaton that has been *deceived* in the collection of facts and materials on which he established his plan of operations; or that Mr. Mylne, after hearing every thing that Mr. Smeaton had to offer, has undertaken to judge of works in a condition from whence their original state cannot now properly be judged of; and by examining many persons concerned and employed in the detail of its execution; and relying on those whose judgments were incompetent to the business; that Mr. Mylne himself, in the forming of these reports, has been *deceived* and drawn into a *precipitate* opinion.

I shall now conclude with observing, that had Sir Walter Blackett's bridge fallen in the day-time, when it could have been observed that the rapidity of the stream formed a fall of five feet, or even half of it, I never would have advised either Mr. Errington or the county to have set about the erection of another bridge at Hexham, either upon piles, or in any other method, unless the sum of money to be expended upon it was unlimited. This single fact would therefore, in the present case, have deterred Mr. Smeaton from proposing the building at all, neither was, nor in its own nature could be known, till the flood that proved the sudden destruction of the last bridge; though it had, without the least damage, withstood a flood when the fall was three feet nine inches, in consequence whereof the water would acquire a velocity of about 900 feet in a minute.

And now, being master of these facts by the fatal destruction of this work also, he is unwilling to injure his reputation by the disappointment of others, in attempting to erect another bridge at Hexham upon a limited sum: that post of honor he leaves to be occupied by some more hardy or fortunate adventurer, remembering that a burnt child dreads the fire.

Grape Inn,
28th June 1788.

To

To Mr. Donkin.

Sir,

Austhorpe 7th Feb. 1784.

As I heard nothing for so long after the sessions, I flattered myself that Mr. Errington's offer had been accepted.

It is, as you observed, now reduced to this, that Mr. Errington must either rebuild or acquit himself by law; but it is well worth very seriously weighing, whether, to avoid the disagreeable uncertainty of a law-suit by rebuilding, Mr. Errington will not as certainly incur the disagreeableness of both rebuilding and a law-suit into the bargain; for it appears to me, from the temper and disposition of his opponents, that they will dispute every step that he takes, and if they so conceive it not to be *strictly* done in conformity with the contract, he will be equally liable to be harassed by an action for non-conformity in part, as for non-conformity in the whole. Let us now, therefore, review the ground on which he will stand upon each of these points.

If he lets the matter go to a jury upon a non-compliance to rebuild, I wish Mr. Errington would be advised by the most able genius in the law upon the point; as to me, it very strongly appears, that were I a jurymen in the cause, I never could consent to a greater sum in damages to the county (notwithstanding the penalty), than the sum he actually received from the county, because, ■ it will undoubtedly appear sufficiently in evidence, that for the purpose of reinstating the bridge, the materials now upon the place and in their place, are of considerably more value than those Mr. Errington received from the county, notwithstanding their valuation; and if it be true that the law of England is founded in reason, which the law-men strongly contend, that is, in natural justice, it never can be conformable to either justice or reason, that a sum in damage should be given to the county beyond the sum in which the county is really damaged; because in that case the penalty of the bond would be made to operate as a punishment upon ■ person who has honestly endeavoured to fulfill his contract, and who in fact has once fulfilled it to the full content of the other contracting party, and becomes obnoxious to a penalty for no other reason but because he has been so unfortunate as to have his work destroyed by an act of Providence, which no human foresight could investigate or guard against*.

* In other cases the law does not extend the penalty beyond the damage sustained, for in the case of the common obligation for money borrowed, though the penalty is for double the sum, yet no more is recovered than the sum borrowed and interest. And why so? Because it would be contrary to reason and natural justice to make a man pay more than he borrowed, merely because he failed in doing it at the day. And I am very apprehensive, that there will not be found a determined case *strictly parallel* to the present, where it has been otherwise determined; and if not, this case being a new one, must stand upon the natural ground of the common law, that is, reason and natural justice.

U u 2

Mr.

Mr. Mylne may talk of the works not having been founded *deep enough*, and that it is uniformly a found gravel, because he found it so on a trial in a place where that had a knowledge of the situation would have doubted it; but though for argument sake, it should be admitted for *the present*, that the gravel was equally compact to an unfathomable depth *quite across* the river, as in the place where he bored, yet we have now the authority of Mr. Mylne to say that this gravel, though "hard to the touch of boring, compact to the eye and feeling of instruments, is wonderfully loose and unconnected in its parts." — If so, is certainly unable to resist the violence of the floods of the Tyne, which Mr. Mylne very emphatically confirms further, by adding, "inasmuch that the bed of the river Tyne seems to shift and alter its form, extent, and situation with every flood, more or less, and tearing up at one time to a great depth that fair molded and well-laid hollow that the stream laid for itself on some former occasion." Now this being so, to what purpose to drive piles into a body of gravel, if that body is itself liable to be taken away, into which the piles are driven? It is necessary then that this body of gravel should be prevented from moving by the deposition of some matter more compact than the gravel itself, to be able to resist the violence of the floods, and protect the ground underneath.

This was indeed done by the deposition of rubble stones from Oakwood bank quarry, which deposition of rubble is not only in general the most effectual method my experience has furnished, of protecting a gravel soil from the wash of a violent current, but I esteem the rubble of Oakwood bank quarry of the best quality for this purpose that I have seen. The works were amply guarded with this stone; and so satisfactorily so that I did not think any flood of the Tyne would or could have moved them; and I thought them still the more secure after having resisted the velocity of 900 feet per minute, without the least derangement, but on the contrary, rendered the whole more even and compacted by the interstices being filled up smooth and even with gravel and matter of a lesser size. Had this defence of Oakwood bank quarry rubble laid still there was nothing perishable in the bridge to be any cause of decay; but a flood comes so rapid and sudden that its velocity, amounting to 1000 feet per minute, was sufficient to move the defence of the Oakwood rubble, and so even and equally was it distributed that the failure of all the parts dependent thereon was in a manner together.

Mr. Mylne entertains an idea, that if our works had been founded deeper they would have fared better; and so far I agree with him in opinion, that had they been as deep again, they might have stood an hour longer: but when we know that the river Tyne

is capable on every flood, more or less, of tearing up that fair moulded hollow (I suppose means the channel of the river) to a great depth, it perhaps may be very difficult to ascertain what depth will be out of the reach of its action; nor is this difficulty rendered the less by his shifting the resolution of this very difficult question from himself to us. I know a part of this river where the water has gulled away its bed (as well as remember it, on measure) to the depth of *at least* below the low state of the water's surface.

I have thought it proper to say thus much by way of obviating those hints and surmises which tend to make it seem as if any thing had not been done that could be done in the situation.

I come now to consider what ground Mr. Errington stands upon in case of rebuilding; and here it strikes me, that not only Mr. Mylne, but every one else also, has considered this matter in the same light as if it had never been done, that is, considering how Mr. Errington was to acquit himself of the whole agreement: whereas the bridge has been built complete, and to the entire satisfaction of all the contracting parties, according to the agreement, and so certified by two magistrates as therein appointed: had, therefore, the last covenant been omitted, which obliges Mr. Errington to maintain and uphold for seven years after the magistrates' certificate, he would most certainly have stood acquitted as having fully performed his contract. It would, therefore, seem to me, that what remains obligatory in the contract is what remains so in force of the last clause, and it would further seem to me, that in an unfortunate case, like the present, where the thing has once been satisfactorily done, that a liberality of construction of this last clause cannot be extended in disfavor of Mr. Errington, but rather, as far as the nature of the thing will reasonably admit, in his favour.

I should therefore wish that the following queries were submitted to some genius in the law.

1st, As a considerable part of the bridge is left standing and unhurt, whether, if more favourable in point of construction to Mr. Errington, this may not be placed under the idea of an obligation to *repair* in contradistinction to that of *rebuilding*?

2dly, Whether the words of the contract *uphold, support, repair, maintain, and keep in good and substantial repair* the said bridge, will oblige Mr. Errington to make the bridge exactly

exactly what it was before, or strictly conformable to the design annexed to the contract, and to which it refers, notwithstanding that from the nature of the accident, the ground of the site is so altered that an exact restitution is now impracticable?

3dly, Whether Mr. Errington (having once acquitted himself in point of satisfactory construction) is obliged (further than he may think necessary for his own security) to make any additional defences, or to bear at greater expenses in rendering the foundation more secure than it was before, but may do the work in the same way it was before, where that can be done; and where change of circumstances has rendered that impracticable, in any other equivalent way, in the judgment of Mr. Smeaton, to whom the whole matter by the agreement has been referred, and confirmed by act of parliament?

4thly, Whether Mr. Errington may not, for his own security, take any other method of rebuilding any of the particular parts deranged, that from change of circumstances shall be, in the judgment of Mr. Smeaton, more likely than the former to render the work permanent?

5thly, Whether the words *good and sufficient repair* are not qualifying words which will enable Mr. Errington to make use of the old materials in the places where they are now at rest though not in the same position in which they were originally built; inasmuch that had the flood turned some of the pillars topsy turvy, whether they may not be made use of in part of the re-erection, provided that, in the judgment of Mr. Smeaton, they are or can be rendered as secure as in the original construction; though in point of position they will not be strictly conformable to the original design referred to, but will be made as safe and effectual for the use of His Majesty's subjects as a bridge, as if every thing were restored to what it was at first?

6thly, Whether, in virtue of the words "good and effectual repair," Mr. Errington may not in this repair omit every expense that is merely ornamental, in case he so chuses?

7thly, As the risk of the bridge's standing after the repair, lies with Mr. Errington for a certain term, in which, if it should fail, he will be obliged to repair *toties quoties*, whether in case he again employs Mr. Smeaton, and Mr. Smeaton will again engage in the concern, whose judgment, by the agreement, is made the *dernier resort*, whether this will not bar all interference and controul of the magistrates as to the modes to be pursued of repair and re-erection of the particular parts that require it?

8thly,

Whether the certificate of the magistrates, and the acquiescence of the whole body paying Mr. Errington the last payment due on such certificate, be not a full bar to the magistrates to any cavil that may be raised now, whether Mr. Errington fulfilled his contract in the erection, which, in reality, he did to the fullest extent, in the judgment of Mr. Smeaton, and which nobody thought of controverting till after the fatal disaster had happened?

9thly, Whether the time that has lapsed by the process of a treaty of composition, which the magistrates have admitted from Mr. Errington, and to which they have never given a final answer till the Christmas quarter sessions held in January 1784, be not to be reckoned in part of the seven years from the time of the certificate, which was at the same time three years before?

10thly, Whether if Mr. Errington, assisted by the judgment of Mr. Smeaton, repair the bridge so as to be in every respect as effectual for use, and as sufficient in point of stability, as the bridge was before the accident, and is so maintained by him to the end of the term to which he is obligated, he will not then be legally discharged from the penalty of the obligation into which he entered?

I beg leave, before I conclude, to declare once more, that, though I never thought it a difficulty to reinstate the bridge upon a principle of permanency equal to what it was at first, yet from the experience of this accident I do not know of any method at any expense within the bounds of Mr. Errington's obligation to reinstate it, so that it shall, in my opinion, have the same prospect of permanency that I thought it had before the accident; yet such a principle of stability as it had before the accident may enable it to stand longer than the lifetime of any man in being, or it may be thrown down again the next year; for as it is out of my power to calculate the uttermost powers that Nature can collect, so it is out of my power to say what will absolutely stand against every possible violence.

Before the accident I thought this bridge had this permanent kind of security; in this, the accident has convinced me that I was mistaken, and that I may be so again: but this I do apprehend, that had there been but one single hour more between the downfall of the snow and rain in the night and the flood's acquiring its greatest violence by the middle of the next day, it would in that time have so filled the reaches of the river below the bridge, as to have moderated its rapidity in passing the bridge from 1000 to 900 feet per minute; so that the bridge would have been standing at this instant, and all

all those concerned in its erection receiving the praise that the public was pleased to attribute to them for so noble an erection, instead of the disgrace attending the being unsuccessful generals.

I remain, Sir,

Your most humble servant,

J. SMEATON.

A DISSERTATION upon the peculiar Hardship of the Case of HENRY ERRINGTON, Esq. in regard to his Bond for the Maintenance of Hexham Bridge for Seven Years.

"GIVE me my Bond," says Shylock; "I will have my Bond." This, though an ancient legendary tale, has been seized upon by that immortal genius Shakespear, and wrought up in a striking degree, to shew to what manifest injustice human laws are capable of, in particular instances, when carried to a rigorous execution in those cases to which, as unforeseen, they never have been intended to be applied. Had the laws of Venice been rigidly carried into execution in the present case, they would have been looked upon with abhorrence by all succeeding ages; but in the way it was determined, we cannot less admire the ingenuity of the pleader, in finding out a circumstance by which the keen edge of the law was taken off, and strict and equal natural justice rendered to all the parties, than the renowned decision of *Solomon* between the two harlots; or the celebrated decision of *Sancho Pancha* between the cook and the defendant.

What, in this case, do the magistrates of the county of Northumberland pursue Mr. Errington in an English court of justice to obtain? Why, to obtain the payment of 9000*l.* from a person who never received from them more than 5700*l.* Do the magistrates then mean to make money of Mr. Errington for the benefit of the county's purse, merely because they have caught him upon the hip? No; their own honour, jointly as well as severally, will not prompt them to avow this. No; they say that they sue Mr. Errington for the penalty of the bond of 9000*l.* to force him to re-erect the bridge, and maintain it for seven years in the terms of the contract. But supposing Mr. Errington to pay the 9000*l.*, will any man undertake to erect a bridge for that sum, to maintain it for seven years, giving a bond for the performance, of 9000*l.*? (It should be 11,000*l.* to be a strict parallel), without

which they will not stand upon the ground Mr. Errington does, nor the county be any better assured of their having a bridge. Certainly no man will, unless he is mad, or in no degree instructed by the lesson the late fatal experiment has taught. Why then, what is the result, but that the magistrates of Northumberland, taking advantage of a particular turn of the law of this kingdom, mean to force a sum out of the pocket of Mr. Errington that he never received, in order to put it into the county's purse, to enable the county, by a further addition of their own, to lay out a sum of money upon a further and more extensive experiment, far greater than Mr. Errington's contract was to receive.

"But," says Shylock, "it was your business to have considered the consequences before you entered upon the bond. You executed the bond with your eyes open, and you must pay the penalty."

But did Mr. Errington enter into this bond with his eyes open? Why, no; he certainly did not. Were any other person now to enter into a similar bond, it may be said, that he really and truly enters upon it with his eyes open; that is to say, with the necessary degree of information to give him some idea of the extent of the difficulties and hazard that were likely to attend it. The late erection may be considered as a proper experiment to prove the degree of rapidity and violence that the river Tyne is subject to so high up in its course as the parts opposite to Hexham; but, previous to this, there was nothing to furnish an adequate idea, much less a positive proof, of the degree of violence of which this river is at times, under certain circumstances, capable.

A bridge new built opposite Hexham, at the upper or western end of the town, of a construction somewhat similar, though (according to the doctrine of some) more secure, as having piles and strong platforms under all the piers, in the compass of a single night, in the inundation that happened in Nov. 1771, was totally taken down and destroyed, nothing remaining the next morning but the north abutment. This will naturally suggest great violence in the river, or great weakness in the construction of the bridge; but to which the catastrophe was principally to be attributed, does not positively appear: for the bridge being apparently right at darkening, and totally demolished at break of day the next morning, nobody happened to be witness of its destruction, or of the fall that the water had in passing the bridge from the up stream side to the down stream side thereof. All that could be seen next morning (the water being then a good deal subsided) was, that from the marks it had left it had been very uncommonly high, and that it had

not

not only taken the south abutment clean away but widened that side of the river by 60 or 70 feet; all which indicate marks of great rapidity and violence, but *what* *free* of it by no means appears: for if the water had rose to the same height, and had been stagnant like a mill pond or tide river at high water, no degree of height or depth of water ought to hurt a bridge that is expressly built not to take any damage from mere wet; nor did any thing appear by which a fall *on* of two feet could be inferred: its failure therefore must appear to be owing not so much to the weakness of the constructed matter of the bridge as to the weakness of the stratum whereon it was founded.

The height of the flood that occasioned the demolition of the last bridge, was in the middle of the day; and the beginning and progress of its fall witnessed by many persons; and before any derangement had happened, it had been remarked what member of the bridge the water was even with on the up stream side, and what member from the down stream side, which from its known dimensions, amounted to near upon five feet of difference of level; so that the water came down in this flood with so much rapidity and suddenness, that not being able to fill the reaches of the river and vallies below so fast as it came down, it formed there a *breast* of the astonishing height or fall of near five feet perpendicular: and from a fall of less than five feet, that is, of four feet five inches, there necessarily results a rapidity of the torrent, amounting to one thousand feet in a minute; a quantity of fall and rapidity, that *could it have been known* from the destruction of the former bridge, or even had there been found a fall of *half this quantity*, Mr. Smeaton can take upon him to say, it would have deterred him from encouraging Mr. Errington to have had any thing to do with undertaking the proposed bridge: so that it may be fairly said, that neither Mr. Errington, nor any of his advisers, either had or could have that degree of information as to warrant its being said, that Mr. Errington executed the bond with his *eyes open*: but any one now that enters upon a similar obligation must enter into it with his eyes open; because from the late fatal experiment, he will know this *capital and leading maxim*,—that by the sudden melting of snow, accompanied with a violent downfall of rain, pouring from the steep sides of those hills extending to the very sources of two large rivers that join a little above Hexham, there is a capability of the waters coming down with that sudden violence, as that in the situation of the late bridge, the torrent is capable of forming a breast of near five feet, and consequently, of acting with a certain rapidity of at least a thousand feet per minute; and knowing this for a certainty also, drawn from the same experience, that this velocity is capable, not only of tearing up the bed of the river, but of removing all such rough materials of stone as may be deposited for the defence of the regularly constructed works.

Whoever

Whoever will therefore now undertake to build a permanent bridge, must be provided with such a design as not only will be proof against all the violence and causes of derangement already ascertained and described, but, *■* it cannot be known for a certainty that the violence already experienced is the uttermost that Nature is capable of, in this place, he ought to be still more firmly fortified on that account, to resist such further violences as may possibly happen: all which, in Mr. Smeaton's judgment, cannot be expected to be done for a much larger sum than the penalty of Mr. Errington's bond; much less for the sum of money and value in materials, that Mr. Errington actually received.

Had Mr. Errington drawn the magistrates of Northumberland into the scheme and idea of building a bridge at Hexham, merely to serve his own purposes, and after a very considerable expense to the county, it had ended in the ill-fated catastrophe that has happened; had Mr. Errington had a view to make *■* profit of this business; had he been sparing of any apparently necessary expense for the accomplishment thereof; had he let it by the great, to be executed by under workmen, and thereby eased himself of the trouble and attention necessary to such *■* work, and withal put *■* round sum of money into his own pocket; had he employed incompetent artists to direct and superintend the work, or advised with such, *■* to the practicability and mode of accomplishing it, who were not of established reputation in the country for works of the kind;—in short, had Mr. Errington practised or attempted to practise, any fraud in the conduct of this affair, or acted with any sinister views, in any of these cases it would have been natural for the magistrates, finding themselves cheated, deluded, and disappointed, to have pursued Mr. Errington with the rancour and vindictive spirit they are now doing: but if it shall appear that the very reverse of all these things is the truth; if it shall appear that the magistrates had entertained this scheme and idea from the suggestions of the late worthy and universally esteemed and respected Sir Walter Blackett, the upshot of which, as respecting him, was the total demolition of the bridge, as already described, in 1771; if the disappointment arising from this fatal catastrophe was so great to the magistrates, that, on Sir Walter Blackett's refusal to be concerned with the bridge any further, choosing rather to pay the penalty of a bond that he had entered into with the County, than further embark in so ill-fated, in so apparently uncertain and hazardous an undertaking*: I say, if on this refusal of Sir Walter, the magistrates still remained so eager for a bridge that they actually began to erect another near the same place, and for this purpose engaged an eminent engineer to direct and

* Sir Walter Blackett entered into a bond, the penalty whereof was 3000*l.* the identical sum that he received from the County, towards building a bridge at this place. The bridge certainly cost a far larger sum; but the voluntary subscriptions of several gentlemen whose estates lay in that neighbourhood, made a part of the extra sum expended, no part of which was refunded by Sir Walter.

superintend the work †, with a resident surveyor of his own choice and recommender. and if after making some progress in the work, this same engineer gave it up as impracticable, on account of the insufficiency of the foundation; if the magistrates notwithstanding still remained unsatisfied, and eager to that degree as even to attempt to draw in the poor working masons of the county to take this great hazard upon them, (after a declared impracticability by an eminent engineer) to the probable ruin of themselves and families; I say, if, after all this ardour for a bridge on the part of the magistrates, Mr. Errington was the unhappy sacrifice delusively taken in by their offers §; then it may be fairly said, that the magistrates have drawn Mr. Errington into a scrape, and not Mr. Errington the magistrates; and that in taking the thorn out of their side he put it into his own; for which act they are now fully bent to punish his ill success by a rigorous exaction of a sum of money that he never received.

True it is that Mr. Errington had a view, he had a *motive* in this business; but if that motive was a laudable one, why punish his want of success with so much rigour? We do not read of any age where men undertook works for the public service, merely for the sake of having the trouble of performing them; mankind in every age had a *moving cause* of action. Did Sir Walter Blackett engage in building a bridge opposite Hexham without any other moving cause than the mere good of the public? Certainly not. Sir Walter Blackett had a very considerable estate opposite the upper or western part of the town of Hexham, and was lord of the manor of the whole. Had Sir Walter Blackett had no moving cause but the mere *public utility*, to fix the destination of the good he intended to mankind, he might have found many other places to promote the building of a bridge in England, and some in Northumberland; but it must be allowed, that the above cir-

† Mr. John Wooler, who was then rebuilding the bridge of Newcastle, overthrown by the same flood, and which was afterwards finished by him.

‡ Mr. Jonathan Pickernell, from London; afterwards made Surveyor of the County Bridges of Northumberland, and recommended by some of the magistrates to Mr. Errington and Mr. Smeaton, to build Hexham Bridge under his direction.

§ Whoever was the least conversant with the public transactions of this county, in the years 1775 and 1776, will well remember an advertisement coming from the magistrates of this county, and appearing in all the three weekly papers of Newcastle, importing their readiness to treat with any person that would engage to build a bridge at Hexham, according to a design or plan for a *superstructure*, lodged for their inspection with the clerk of the peace. The offerer to be at liberty to pursue his own plan or method of constructing the foundations (under water), but to give security for the permanency thereof for seven years. This was the purport, as it occurs to memory; but the masons and working mechanical artificers were too wise to take the risk of such impending ruin: and the consequence was, that after continuing the said advertisement weekly for the greatest part, if not the whole of a year, without any adequate offer, it was Mr. Errington's ill fate to be seduced by those colours so hung out.

circumstances ought not to take from the merit of Sir Walter's fixing his efforts at Hexham, in building the bridge so as to land, on the north side, upon his own estate.

In like manner, Mr. Errington having an estate opposite to the town of Hexham, on the eastern or lower part of the town, being also desirous to have the bridge to land at the north end upon his estate, the benefit that was likely to accrue thereto was a sufficient inducement to him to engage in that very scene of trouble and attention that must necessarily arise in the building of a bridge in such a situation, and of such a magnitude, without the least prospect of any profit, or other advantage by the building; on the contrary, it was Mr. Errington's professed declaration to Mr. Smeaton, when he applied to engage his advice, opinion, and assistance, that so far from meaning to be a gainer by the undertaking, he should not be disappointed if he were 2 or 300l. out of pocket; and which, it will be proved, actually turned out to be the case.

In regard to the competency of Mr. Smeaton, to form a judgment of and properly execute such undertaking, this may be separately discussed: but it will certainly exculpate Mr. Errington in having employed him, when it is recollected, that at *that time* Mr. Smeaton had had *no bridge fallen*, had been employed in the full scope of business in his profession no less than 25 years, and at that time had given proofs of his abilities by a constant success in executing the most difficult works, in almost every part of Great Britain, without *then* the failure of a *single subject*.

If therefore Mr. Errington acted the part of a wife, a prudent, an upright, and a disinterested man, willing to promote the public good, along with his own; if in a laudable attempt towards this end he has failed, from causes that could not in their *own nature* be foreseen; it must be allowed to be *hard*, nay *very hard* indeed, that Mr. Errington not only cannot be excused in his failure, but he must be actually positively *punished*. Does the law admit no remedy? The law-men say of *none*; nay it is not even in the power of the magistrates to remit any part or tittle of the *penalty of the bond*! so says the *written law* of England!

But what says *natural justice* in the case? that law which is written in the breast of every rational man, and is properly deemed the law of *equity* and of *good conscience*; does this agree in the same determination? No, it revolts from the idea, and says, that to exact the full penalty of the bond in the present case, would be the most shocking injustice to Mr. Errington. Is no one then in a legislative sense, in possession of the executive part of this law of equity, and good conscience? Yes, reason answers, every man in quality of a Bri-

does, that for want of the money at the time, the obligor is prevented from fulfilling a purchase that he has made; by which he would have got a profit equal to the sum, and in failure thereof may himself be subject to an action; and after all this he is put to the necessity of prosecuting an action to recover his own; this is *very hard*, but will a jury punish this obligee for his fraud, failure and neglect by finding in damages the whole penalty? No, they will calculate what his principal and interest comes to; allow him that, with expenses of suit, and give damages accordingly. But here we are told, that this dispensing power in the breast of a jury, is limited in consequence of an *act of parliament*, expressly made for this purpose, so that let the penalty be what it will, the obligor can recover no more than the real pecuniary damage.

Very well; but does not the very making of such an act of parliament infer the judicial power of a jury, that subsisted in their *breasts*, before the act was made? and therefore, where there is no act to fix the line of law, that it still rests in the breasts of a jury? the thing speaks for itself. Acts of parliament are not made to remedy an evil that has never existed. It is not to be doubted, but that before this act, it was common for a designing obligor to trump up a detail of the damages he had suffered, by the money not being duly paid according to the obligation of the bond, in order to extort the whole penalty; and though this might sometimes be the case, that the obligor might suffer by the neglect of the obligee, yet it doubtless would be pretended ten times for once, that it really was the case. It might also happen to some juries not to have that accuracy of reason and discernment, but to suppose themselves under an absolute *obligation* to find the full penalty, though an adequate damage might not be so clearly made out, conceiving the penalty to be the proper punishment for non-performance. In order fully to settle these matters upon the best general grounds, an act has been found necessary to restrain the jury's discretion from proceeding beyond a certain line; and nothing can be a stronger proof of the full extent of a jurymen's power of discretion, than this act of parliament, to restrain it in this particular case. It is not therefore to be doubted, but that every jurymen who is fully sensible of what is due to his own character, and the full extent of Mr. Errington's case, will perceive, that as he has the power, he undoubtedly will have the will, to draw the merciless teeth of the lion, and not suffer them to fix unreasonably deep in the flesh of an innocent man; and this even at the expense of his own oath in giving exaggerated damages, where mitigated damages only are due.

BERWICK BRIDGE.

The REPORT of JOHN SMEATON, Engineer, upon the State of Berwick Bridge, from a View thereof, the middle of September 1771.

Notes taken on View.

THE key from the upper birth to the bridge, appears to be in a ruinous condition.

N.B. The north west abutment wall of the bridge swayed out, and overleaning, it seems proper to be supported by a buttress.

The splay wall up stream wants pointing.

The second course of arch stones in the first arch from Berwick, is decayed in the west face near the crown of the arch; the stones that are perished should be shifted.

The Piers to the fourth inclusive being in hand to be pointed and repaired, and in great part done, it is needless to say any thing as to the reparation thereof.

Fifth Pier—Some stones deficient, and the lower point of the starlings frame beginning to decay, these matters should be attended to.

Seventh Pier—Several stones out of the sides of the pier, and also some stones out of the old starling jetty or frame, as well as the new, which last is settled and considerably deranged.

Ninth Pier—The north side of the starling wants planking, and the upper peach is in bad condition; it may be rebuilt, or with repair, may be expected to last a few years longer.

Tenth Pier—The sheeting on both the north and south side of the starling wants repairing, as also the peak.

Eleventh Pier—The down stream point of the starling is decayed, the north side wants its planking half round, and the south side wants the loose stones righting up against

Twelfth Pier—The down stream point of the starling is out of repair, the sides want planking all round, and the south side more particularly wants repairing.

Thirteenth Pier—The starling wants planking all round, and the loose stones righting up in the passages, and laying regularly against the sides of the starling; the peak of the pier has settled, but with repair may probably last a few years longer.

Fourteenth Pier—The starling wants planking on the north side, and its down stream point is deficient. In the face of this arch arch stones are wanted on the west side, but as they are found in the scottie underneath they are not in imminent danger, and by shifting the decayed stones may be properly repaired.

Several lengths of the parapet of the bridge are overleaning, some of the worst places should be taken down and rebuilt, and the terminating pillars of the abutment parapets on the south end of the bridge being in a state of disrepair, should be made up again to prevent further derangements to the parapets.

N. B. Reference has also been had to the report of Messrs. Wilson, Dods, Buglafs, and Steel, dated 21st June 1771.

This bridge having been built several centuries, has felt the effects of time, and besides the decay of the stones in some particular places, the mortar is in general perished from the joints, as commonly happens to buildings of the same age, and alike exposed. Nothing would so much contribute to an appearance of good repair as to have the joints new pointed, and could this be done in an effectual manner it would in reality contribute to its duration; but the imperfect union of new mortar with old, and with stones in a state of waste, is such, that the frosts and rains in the course of a very few years generally undo whatever of this kind is done, even when executed with great care: however, it being very satisfactory to the public eye to see matters of this kind look well, I cannot but recommend it to those who have the management of the repairs of the bridge, to do as much of this as they can, without neglecting what is really essential.

This bridge, like most of the same age built in tide rivers, has been founded on piles sawn off above low water, for the defence of which from the injuries of the weather, and also to secure the ground round each assemblage of piles for the forming of a pier, each assemblage has been surrounded with another work called a starling or frame, which

terminated so much above low water as to cover the wood work immediately under the pier; and as these starlings are considered only as a work of defence, whose surface is in general wood, they must of course be subject to decay from the injuries of the weather and the wear of the water; the piles in the sides of the starlings in time therefore want renewing, and when that is the case, as they can easier be done by surrounding the former work with a fresh row of piles than drawing out the stumps of the old ones, it happens that the *easiest way* is often taken: but as this increases the bulk of the starlings, and of course contracts the water ways, the rapidity of the flood tends in a greater degree to sap and destroy those outworks, and then recourse is had to stones to secure the starlings, and the intermediate bed of the river, which still increasing the obstruction, form altogether a kind of dam, over which the water falling pools a great hole below the bridge, which often threatens the destruction of the whole. For these reasons I cannot commend the first laying of the stones round the starlings, and less the extending the starlings themselves so far from the sides of the piers as to require it; but when done, as one evil is frequently applied to cure another, perhaps it may not be so perfectly safe just now to take away the surrounding stones already placed; but it is very material that the repair of the starlings should be duly attended to, as the safety of the whole bridge depends upon them; and when any repair is made to do it in such a manner as not to contract the present water way, but whenever it is possible by contracting the starlings sideways to increase it, and whenever the down stream points of the starlings become dangerous, by the pooling of the ground below the bridge, and taking it too much away from the tail of the starlings, it will be the best and cheapest way to secure the bottom by throwing in rough rubble stones from the quarry; and though this may in some sense be considered as a contraction, yet being chiefly in the eddy of the pier, will not have the effect of such, and is to be applied only in such a degree as the matter there has become defective in quantity: it is possible that after such application some of these stones, by being laid too steep against the starlings, may be carried down by the succeeding floods; but as this will only happen by their being too steep, by sliding down they enlarge their base, and by filling up the place from whence they have slid, they will in the end remain immovable like a rock.

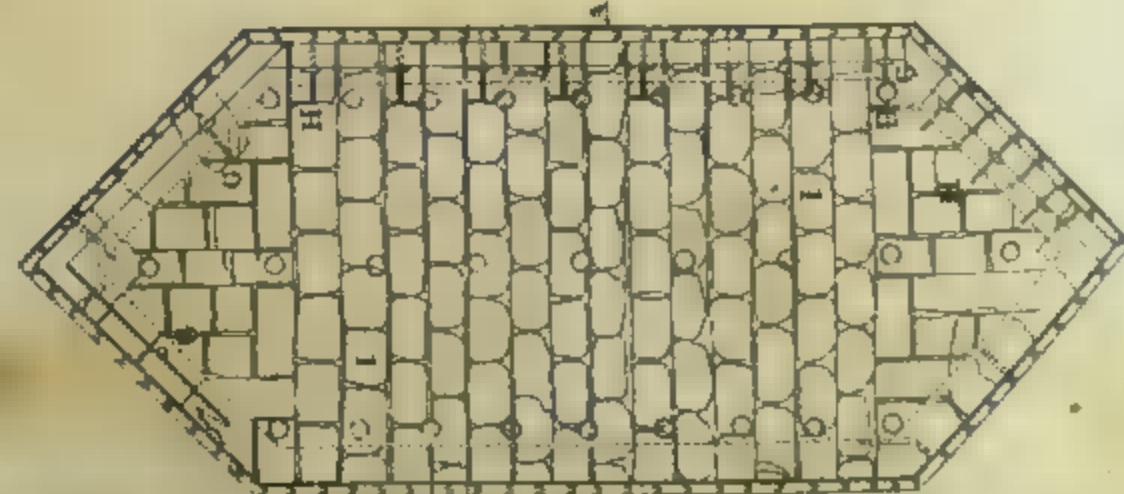
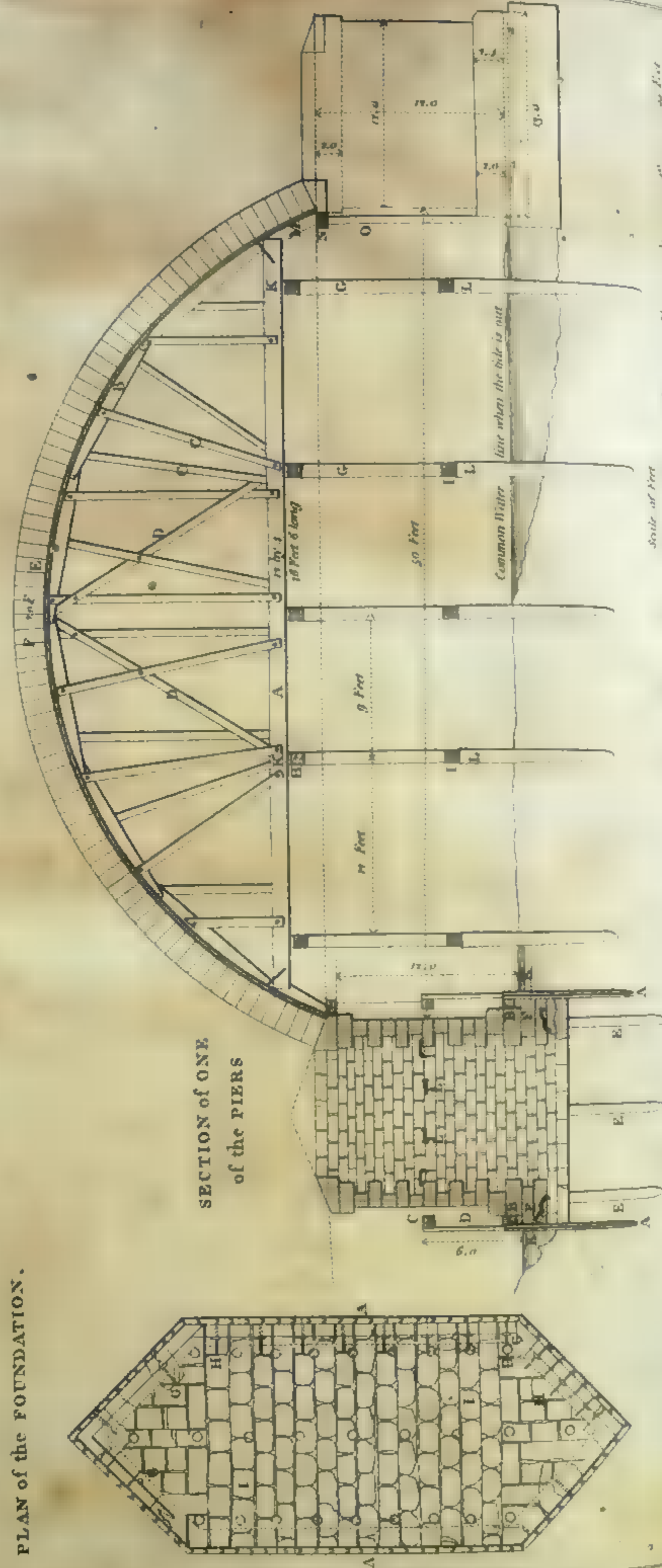
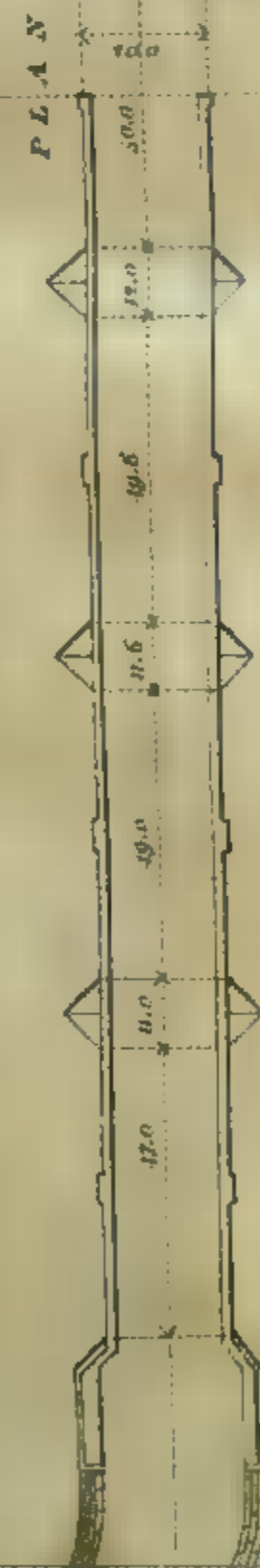
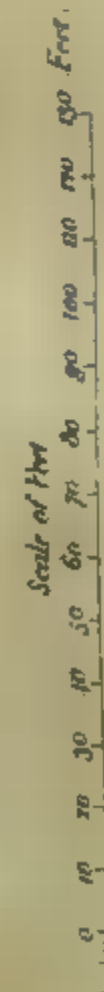
By attempting to put the stones into a frame at the tail of the seventh starling for the security of the down stream part of that starling, in the case above mentioned, and for want of something to keep the ground from being carried away round this new jetty, it has settled and the stones therein have become deranged; but if the wood work could be drawn out, and the stones suffered to form their own slope, and fresh

stones added where they may be defective, I apprehend this starling would be effectually secured.

In regard to the up stream peaks of the piers which have settled and cracked, as the arches do not immediately depend upon them, the building thereof is a matter less pressing, especially when it is considered how difficult it is to unite the new work with the old, so as to prevent a separation even after they are rebuilt.

J. SMEATON.

Ausborne,
16th June 1772.



BANFF BRIDGE.

(See Plate 14.)

ESTIMATE for building a Bridge over the River Doveran near Banff, to be of 410 Feet between the Abutments, 20 Feet wide over all, and to consist of Seven Arches; the Aisler of the Piers, Arches, and Facings of Freestone, and the Core of the Piers, Spandrell Walls, and Parapets of Rubble.

PREPARATION for founding the PIERS.

PREPARATION for founding the PIERS.		£.	$s.$	$d.$
To timber in coffer dams for the six piers and two abutments, exclusive of what is to remain connected therewith, 1278 cube feet at 3s. 6d.		223	13	0
To iron work to do. 12 cwt. 2 quarters, at 5d. per lb.	- - -	29	3	4
To pumps, piling machines, and utensils	- - -	100	0	0
		352	16	4

The PIERS and ABUTMENTS to the Spring of the ARCHES.

The PIERS and ABUTMENTS to the Spring of the	120	0	0
To excavations and pumping for eight foundations at 15 <i>l</i> .			
To timber in plank piles, bearing piles, ribbands, &c., for the eight foundations, 2788 cube feet, at 4 <i>s</i> .	557	12	0
To iron work for the six piers and two abutments, 22 cwt., at 5 <i>d</i> .	51	6	8
per lb.	9	6	8
To lead 10 cwt., at 2 <i>d</i> . per lb.			618 5 4
To aifler in 14568 cube feet, at 6 <i>d</i> .	364	4	0
To rubble work in do. 82 roods Scots, at 4 <i>l</i> . 16 <i>s</i> .	393	12	0
To 2 <i>d</i> . per foot extra upon 4024 cube feet of rubble blocks to serve in the inside for the bottom, tie and bond courses as aifler	33	10	8
To 50 tons of Pozzelana, at 3 <i>l</i> . per ton, ground and sifted ready for use	150	0	0
			941 6 8
To 450 cube yards of rubble to be deposited round the piers for securing the bottom, at 1 <i>s</i> .			22 10 0
			2054 16 4
Total of piers and abutments,			

The SUPERSTRUCTURE.

£ s. d. £ s. d.

To centering for the arches which contain at a medium 1220 feet superficial in the soffite, and for seven arches 8540 feet, at 10d. -	355		
To asfler in the arches, which at two feet thick contain 17080 cube feet, at 6d. -	427	0	0
To asfler in the capings and facings 4792 feet at 6d. -	119	16	0
To rubble work in the whole superstructure, 117 roods, at 4l. 16s. including scaffolding -	499	4	0
To extra work 16787 feet, face measure of rubble walling in the spandrells, abutment walls, and parapets, 1d. -	69	18	11
To cramps and lead for the capping -	15	8	0
To filling the spandrells and abutments with quarry and levelling the whole length of the bridge with gravel, 2417 roods, at 6d. -	60	8	6
	1191	15	5
Total of the superstructure,	1547	12	1

The TERMINATING SLOPES by way of Access to the Bridge.

To dry rubble building wharf walls for confining the forced earth at the north-west end of the bridge, containing 25½ roods, at 3l. per rood -	76	10	0
To rubble parapets in mortar to do. at 4l. 16s. -	21	12	0
To extra work on 400 feet running of rubble capping and base of the parapets, at 3d. -	5	0	0
To gravel, &c. for levelling the south east end of the bridge, and for forming the slope on the north west end, so as not to be steeper than one in twelve, containing 3400 cube yards, at 6d. -	85	0	0
	188	2	0

ABSTRACT.

The piers and abutments -	2054	18	4
The superstructure -	1547	12	1
The terminating slopes -	188	2	0
Neat estimate	3790	12	5
Contingencies on the above at 10 per cent. -	379	1	3
The above being supposed to be performed by those who are expert in this kind of works, we may add for surveyors and profit of undertakers or inexperience of workmen 10 per cent. more -	379	1	3
Total,	4548	14	11
	N. B.		

N. B. The above estimate is on supposition that every thing is to be provided, and nothing to remain; but a considerable quantity of old materials of the late bridge has been preserved and deposited near the place; I suppose to the amount of 200l.; and the timber of the centers and coffer dams will remain at last to be disposed of.

A quarry very near the bridge, which affords excellent rubble, greatly contributes to the smallness of expense for so large a building.

J. SMEATON.

Auslhorpe,
19th February 1772.

EXPLANATION of the manner of laying the Foundations for the Bridge of Banff.

A—Plank piles encasing the pier and serving as a coffer dam for laying the foundation.

B—String piece first laid for regulating and connecting the plank piles above the common surface of the water.

C—Another string piece for connecting the tops of

D—Planking for keeping out the tide water.

The inside is then to be excavated to the depth required.

E—Bearing piles to be increased or diminished in number, length, or size, according as the ground is found more or less firm: those drawn will do for a middling gravel.

F—A ribband or string piece which is to be adapted to the inside of the piles, and with screwed bolts, (whose threads lay hold of the planks on the outside, but go freely through the ribband) to be fixed to every other plank, and as many of them as are here represented like.

G—Are

G—Are bolts with flat shoulders, and an eye in the head, by which they are tied with cramps to

H—Blocks of rough stone holding the cramps for tying in the outside casing firmly to the pier.

I—Flat rubble blocks for the ground course to tie the base together.

When the pier is raised above low water mark, then the upper part of the coffer dam with its string piece, cross beams, &c., are to be removed, and made to serve for another pier, the plank piles are to be cut off with chizzels at the dotted line K, five or six inches under water, and then the string piece B, comes away and serves for the next pier.

The outside must be guarded with rubble round the casing.

N. B. By way of easing the driving of the plank piles, the ground should be excavated somewhat wider than the pier, and as deep as the water will permit.

The plank piles (which are four inches thick) will be best made of beach, which can be had in planks of proper dimensions from Sussex.

J. SMEATON.

*Ausborne,
19th February 1772.*

EXPLANATION of the Center for the Bridge of Banff.

THIS design shows how it will stand under the middle arch of 50 feet span.

A—One of the tie beams for framing one of seven similar ribs.

B—One of the curbed fellies, there being six in each rib.

C. C—

CC—Struts or props of Scots firs about six inches diameter in the middle, and of their natural taper.

DD—Two braces in each rib for throwing part of the weight of the middle upon the two adjacent supports.

E—Shews the ends of two-inch planks for covering the center.

F—The vaufours or penstones upon the centers two feet in height.

GG—Pillars or props of Scots firs of their natural taper, ten inches diameter in the middle: as there are shewn five under each rib, they will be seven deep, and each row of seven framed into head and fell pieces, whose ends are shewn at

HI—Ten inches square, and 20 feet long.

KK—Denote short blocks of about five inches in height laid perpendicularly over each of the pillars above mentioned, so as to level up the tie beams to their proper height, which blocks are split away from under the tie beams on striking the centers.

The pillars G G are of such a height that the frames H G I standing upon the ground will support the center when the two arches next the town are built (the length of the tie beam A being adapted to the span of the smallest arches), in which case large flat stones well bedded upon the gravel, one correspondent to each pillar G, will sufficiently support the fell pieces I; but as the arches will rise higher, and especially those which are over the channel of the river at low water will be more safely supported by

LL—Piles of Scots fir about 10 inches in the middle, driven into the gravel five or six feet more or less, till they make a considerable resistance to the ram; they are to be driven in rows as nearly correspondent to the present places of the pillars G as may be, and then their heads levelled down so as to suffer each fell piece I to lay true upon each row of seven piles.

M—Curbed pieces answerable to each rib, put in so as to make out the center from the smallest to the greatest arches; these rest upon a plate piece whose end is represented at N, which are each of them supported by seven stanchions or props O, standing upon

VOL. III.

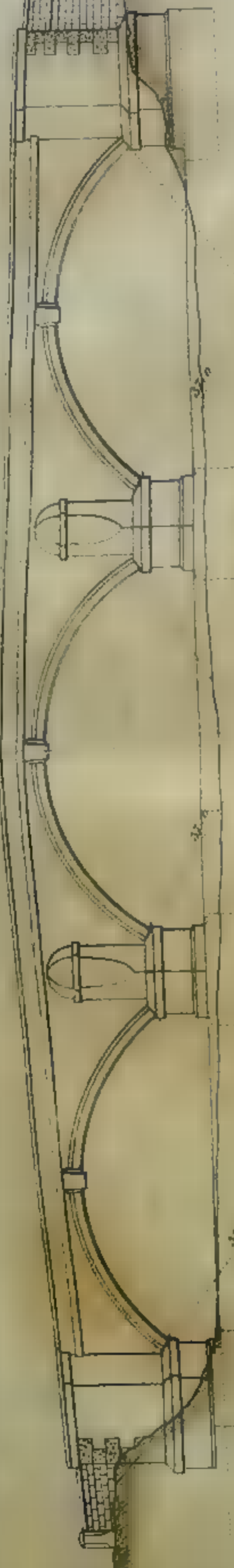
Z z

upon the lowest offsett of the base of the piers, which may be of Scots fir five or six inches diameter in the middle.

To prevent confusion, the stays that will be necessary to keep the work in place while putting together, I have omitted, as these will be obvious to every carpenter, but it is to be noted that every thing of this kind below the tye beams must be struck away after the center is got together to prevent resistance to speats, in case these should happen while the center is up.

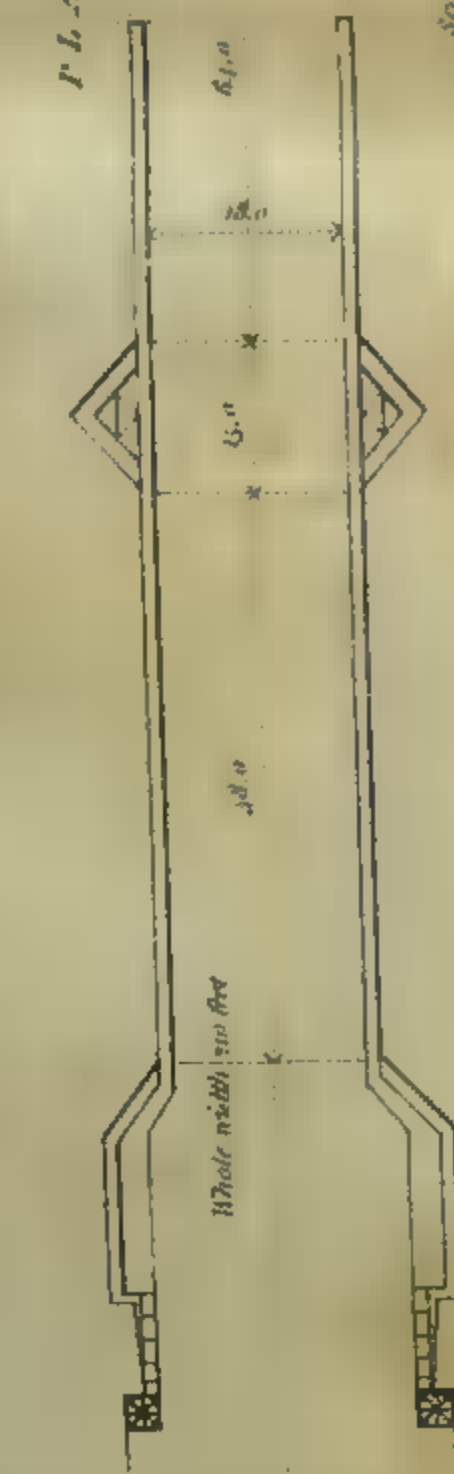
J. SMEATON.

Austhorpe,
31st December 1772.



DESIGN for the BRIDGE of DUMBALLOCH over the RIVER BEWLIE 1772.

PLAN



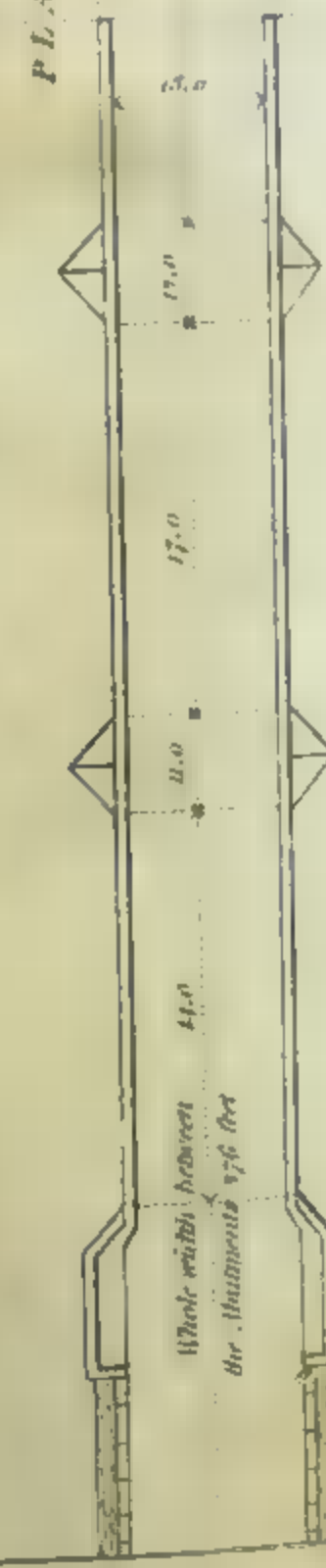
Scale of Feet 0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150

ELEVATION



DESIGN for the BRIDGE of BRAAN over the RIVER CONNON.

PLAN



Scale of Feet 0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150



DUMBALLOCH BRIDGE.

(See Plate 15.)

ESTIMATE for building a Bridge over the River Bewlie at Dumballoch, being 210 Feet between the Abutments, 20 Feet wide over all, and to consist of Three Arches to be built with Freestone.

PREPARATION for founding the PIERS.

	£.	s.	d.	£.	s.	d.
To timber for coffer dams for two piers and two abutments (exclusive of what is to remain connected therewith), 783 cube feet, at 3s. 6d.	137	0	6			
To iron work for do. 7 3, at 5d. per lb.	18	1	8			
To pumps, piling machines, and utensils	120	0	0			
Total of the Preparations	275	2	2			

The PIERS and ABUTMENTS to the Spring of the ARCHES.

To excavations and pumping for the four foundations, at 20l. each	80	0	0			
To timber in plank piles, bearing piles, ribband, &c. for the four foundations, 2568 cube feet, at 4s.	513	12	0			
To iron work for two piers and two abutments, 12 cwt. 3 qrs., at 5d. per lb.	29	15	0			
To lead, 6 cwt., at 2d. per lb.	5	12	0			
Total of the Foundations	548	19	0			
To ailer in do. 12,304 feet (the leading being supposed not to exceed one mile) at 6d.	307	12	0			
To rubble work in do. 64 roods Scots, at 5l. 10s.	352	0	0			
To 2d. per foot extra upon 3600 cube feet of rubble blocks, to serve in the inside, for the bottom, top, and bond courses	30	0	0			
To 35 tons of Pozzelana, ground and sifted ready for use, at 3l. 3s.	110	5	0			
To 1432 cube yards of rubble, to be deposited round the piers for securing the bottom, at 1s. 6d.	107	8	0			
Total of the Foundations	907	5	0			
Total of the Foundations	1811	6	2			

The SUPERSTRUCTURE.

To centering for the arches, which contain in the whole 4200 feet of soffite, at 1s.	210	0	0			
To ailer in the arches, which at 2 4 thick contain 9800 cube feet, at 6d.	245	0	0			
To ailer in the capings and facings, 2650 feet, at 6d.	66	5	0			

Carried forward

	£.	s.	d.	£.	s.	d.
Brought forward						
To rubble work in the whole superstructure 71 roods, at 5 <i>l.</i> 10 <i>s.</i>	390	10	0			
To extra work upon the face of the spandrells, abutments, walls, and parapets, 9606 feet, at 3 <i>d.</i>	120	1	6			
To lead and iron for cramping the caping	8	8	0			
Fitting the spandrells and abutments with quarry scraps, and levelling the whole with gravel, containing 1921 yards, at 5 <i>s.</i>	96	1	0			
				926	5	6
Total of the superstructure				1136	5	6

The TERMINATING SLOPE at the South End of the Bridge, and Access on the North.

To dry rubble building in the wharf walls for confining the forced earth at the south end, containing 13½ roods, at 3 <i>l.</i> 10 <i>s.</i>	47	5	0			
To rubble parapet in mortar 1½ roods, at 5 <i>l.</i> 10 <i>s.</i>	8	5	0			
To extra work on 270 feet running of caping and base, at 3 <i>d.</i>	3	7	6			
To 1500 cube yards of gravel for levelling the north end, and forming the slope on the south end so as not to be steeper than 1 in 12, at 6 <i>d.</i> per yard	37	10	0			
				96	7	6

ABSTRACT.

The pier and abutments	1811	6	2			
The superstructure	1136	5	6			
The terminating slopes	96	7	6			
				3043	19	2
Contingencies on the above, at 10 per cent				304	7	10
The above being supposed to be performed by those who are expert in this kind of works, we may add, for surveyors and profit of undertakers, or inexperience of workmen, 10 per cent. more				304	7	10
Total				3652	14	10

N. B. The above estimate supposes that rubble stone can be procured at 1*s.* 6*d.* per rood of wall laid down in place, and lime at 10*d.* per boll: if those materials cannot be procured at those prices, allowance must be made in the estimate upon them for the difference.

J. SMEATON.

Auslborpe,
19th Feb. 1772.

N. B. The foundations for this bridge are to be laid in the same manner as for Banff bridge.

BRAAN BRIDGE.

(See Plate 15.)

ESTIMATE for building a Bridge over the River Conon at the Boat of Braan, to be 276 Feet between abutments, 20 Feet wide over all, and to consist of five Arches; the Aisler of the Piers, Arches, and Facings to be of Freestone, and the Core of the Piers, Spandrell Walls, and Parapets of Rubble.

	£.	s.	d.	£.	s.	d.
PREPARATION for founding the PIERS.						
To timber in coffer dams for the four piers and two abutments, exclusive of what is to remain connected therewith, 340 cube feet, at 3 <i>s.</i> 6 <i>d.</i>	59	10	0			
To iron-work to do. 3 cwt. 2 qrs., at 5 <i>d.</i> per lb.	8	3	4			
To pumps, piling machines, and utensils	120	0	0			
				187	13	4
The PIERS and ABUTMENTS to the Spring of the ARCHES.						
To excavations and pumping for six foundations, at 20 <i>l.</i> each				120	0	0
To timber in plank piling, bearing piles, ribbands, &c. for the foundations, 3162 cube feet, at 4 <i>s.</i>	632	8	0			
To iron work for the four piers and two abutments, 16 cwt. 2 qrs., at 5 <i>d.</i> per lb.	38	10	0			
To lead, 7 cwt. 2 qrs., at 2 <i>d.</i> per lb.	7	0	0			
				677	18	0
To aisler in do. 15,120 cube feet (the leading being supposed not to exceed one mile), at 6 <i>d.</i>	378	0	0			
To rubble work in do., 65 roods, at 5 <i>l.</i> 10 <i>s.</i>	357	10	0			
To 2 <i>d.</i> per foot extra upon 4602 cube feet of rubble blocks to serve in the inside, for the bottom, tie, and bond courses, as aisler	38	7	0			
To 40 tons of Pozzelana, at 3 <i>l.</i> 3 <i>s.</i> per ton, ground and sifted ready for use	126	0	0			
To 1152 cube yards of rubble, to be deposited round the piers for securing the bottom, at 1 <i>s.</i> 6 <i>d.</i>	86	8	0			
				986	5	0
Total to the piers and abutments				1971	16	4

The SUPERSTRUCTURE.

To centering for the arches, which contain 5780 superficial in the soffite, at 8 <i>d.</i>				192	13	4
To aisler in the arches, which at two feet thick contain 11,560 cube feet, at 6 <i>d.</i>	289	0	0			
Carried forward						

	£.	s.	d.	£.	s.	d.
Brought forward						
To rubble work in the whole superstructure 71 roods, at 5 <i>l.</i> 10 <i>s.</i>	-	390	10	0		
To extra work upon the face of the spandrells, abutments, walls, and parapets, 9606 feet, at 3 <i>d.</i>	-	120	1	6		
To lead and iron for cramping the caping	-	8		0		
Fitting the spandrells and abutments with quarry scraps, and levelling the whole with gravel, containing 1921 yards, at 5 <i>s.</i>	-	96	1	0		
				926	5	6
Total of the superstructure				1136	5	6

The TERMINATING SLOPE at the South End of the
Bridge, and Access on the North.

To dry rubble building in the wharf walls for confining the forced earth at the south end, containing 13½ roods, at 3 <i>l.</i> 10 <i>s.</i>	-	47	5	0		
To rubble parapet in mortar 1½ roods, at 5 <i>l.</i> 10 <i>s.</i>	-	8	5	0		
To extra work on 270 feet running of caping and base, at 3 <i>d.</i>	-	3	7	6		
To 1500 cube yards of gravel for levelling the north end, and forming the slope on the south end so as not to be steeper than 1 in 12, at 6 <i>d.</i> per yard	-	37	10	0		
				96	7	6

ABSTRACT.

The pier and abutments	-	1811	11	2		
The superstructure	-	1136	5	6		
The terminating slopes	-	96	7	6		
				3043	19	2
Contingencies on the above, at 10 per cent	-	304	7	10		
The above being supposed to be performed by those who are expert in this kind of works, we may add, for surveyors and profit of undertakers, or inexperience of workmen, 10 per cent. more	-	304	7	10		
Total				3652	14	10

N. B. The above estimate supposes that rubble stone can be procured at 1*s.* 6*d.* per rood of wall laid down in place, and lime at 10*d.* per boll: if those materials cannot be procured at those prices, allowance must be made in the estimate upon them for the difference.

J. SMEATON.

Austhorpe,
19th Feb. 1772.

N. B. The foundations for this bridge are to be laid in the same manner as for Banff bridge.

BRAAN BRIDGE.

(See Plate 15.)

ESTIMATE for building a Bridge over the River Conon at the Boat of Braan, to be 276 Feet between abutments, 20 Feet wide over all, and to consist of five Arches; the Aisler of the Piers, Arches, and Facings to be of Freestone, and the Core of the Piers, Spandrell Walls, and Parapets of Rubble.

PREPARATION for founding the PIERS.	£.	s.	d.	£.	s.	d.
To timber in coffer dams for the four piers and two abutments, exclusive of what is to remain connected therewith, 340 cube feet, at 3 <i>s.</i> 6 <i>d.</i>	-	59	10	0		
To iron-work to 3 cwt. 2 qrs., at 5 <i>d.</i> per lb.	-	8	3	4		
To pumps, piling machines, and utensils	-	120	0	0		
				187	13	4
The PIERS and ABUTMENTS to the Spring of the ARCHES.				120	0	0
To excavations and pumping for six foundations, at 20 <i>l.</i> each	-					
To timber in plank piling, bearing piles, ribbands, &c. for the foundations, 3162 cube feet, at 4 <i>s.</i>	-	632	8	0		
To iron work for the four piers and two abutments, 16 cwt. 2 qrs., at 5 <i>d.</i> per lb.	-	38	10	0		
To lead, 7 cwt. 2 qrs., at 2 <i>d.</i> per lb.	-	7	0	0		
				677	18	0
To aisler in do. 15,120 cube feet (the leading being supposed not to exceed one mile), at 6 <i>d.</i>	-	378	0	0		
To rubble work in do., 65 roods, at 5 <i>l.</i> 10 <i>s.</i>	-	357	10	0		
To 2 <i>d.</i> per foot extra upon 4602 cube feet of rubble blocks to serve in the inside, for the bottom, tie, and bond courses, as aisler	-	38	7	0		
To 40 tons of Pozzelana, at 3 <i>l.</i> 3 <i>s.</i> per ton, ground and sifted ready for use	-	126	0	0		
To 1152 cube yards of rubble, to be deposited round the piers for securing the bottom, at 1 <i>s.</i> 6 <i>d.</i>	-	86	8	0		
				986	5	0

Total to the piers and abutments

The SUPERSTRUCTURE.				192	13	4
To centering for the arches, which contain 5780 superficial in the soffite, at 8 <i>d.</i>	-					
To aisler in the arches, which at two feet thick contain 11,560 cube feet, at 6 <i>d.</i>	-	289	0	0		
Carried forward	£					

	£.	s.	d.	£.	s.	d.
Brought forward						
To ailer in the capings and facings, 3060 feet, at 6d.	-	76	10	0		
To rubble work in the whole superstructure, 92 roods, at 5l. 10s., including scaffolding	-	506	0	0		
To extra work upon 11,664 feet, face measure, of rubble walling in the spandrells and abutments, walls and parapets, at 3d.	-	145	16	0		
To cramps and lead for the capping	-	11	4	0		
To filling the spandrells and abutments with quarryscraps, and levelling the whole length of the bridge with gravel, 2384 yards, at 1s.	-	119	4	0		
				1147	14	0
Total of the superstructure				1340	7	4

The TERMINATING SLOPES, by way of Access to the Bridge.

To dry rubble building in wharf walls for confining the forced earth at the ends of the bridge, containing 14 roods, at 3l. 10s.	-	49	0	0		
To rubble parapets in mortar, to do. 2½ roods, at 5l. 10s.	-	15	2	6		
To extra work on 384 feet running of rubble capping and base of the parapets, at 3d.	-	4	16	2		
To gravel, &c. for making the access to the bridge, and for forming the slopes so as not to be steeper than 1 in 12, viz. 2048 yards, at 6d.	-	51	4	0		
				120	2	6

ABSTRACT.

The piers and abutments	-	1971	16	4		
The superstructure	-	1340	7	4		
The terminating slopes	-	120	2	6		
Neat estimate		3432	6	2		
Contingencies on the above, at 10 per cent.	-	343	4	7		
The above being supposed to be performed by those who are expert in this kind of works, we may add, for surveyors and profit of undertakers, or inexperience of workmen, 10 per cent. more	-	343	4	7		
Total		4118	15	4		

N. B. The above estimate supposes that rubble stone can be procured at 1s. 6d. per rood of wall laid down in place, and lime at 10d. per boll: if those materials cannot be procured at those prices, allowance must be made in the estimate for them upon the difference.

Austhorpe,
19th Feb. 1772.

J. SMEATON.

N. B. The foundations for this bridge are to be laid in the same manner as Banff bridge.

ALTGRAN BRIDGE.

ESTIMATE for building a Bridge over the River Altgran, near above the present Wood Bridge, to consist of One Arch of 44 Feet Span.

To excavation for the abutments and laying the water for laying the foundations	£.	s.	d.
To aisser in the abutments to the spring of the arch, 392 feet, at 6d.	-	5	0
To do. in the arch, 1800 feet, at 6d.	-	9	16
To do. in the facings, 302 feet, at 6d.	-	45	0
Rubble work in the whole, 11 roods, at 4l.	-	7	11
Centering for the arch, supposed to be brought from the bridge at Braan	-	44	0
Filling the spanurells and levelling the bridge with gravel	-	15	0
		3	7
		129	14
To 5 loads of dry rubble walling to wharf up the slopes	-	12	10
To 548 yards of earth for forming the slopes	-	6	17
Total	£.149	1	6

N. B. It is probable the work may be undertaken for less money, but the quantities may nearly be depended upon.

The above estimate supposes the rubble stone can be procured at 1s. 6d. per rood of wall laid down in place, and lime at 10d. per boll: if those materials cannot be procured at those prices, allowance must be made in the estimate upon them for the difference.

J. SMEATON.

Austhorpe,
19th February 1772.

BRIDGES AT BEWLIE, CONON, ALTGRAN, &c.

THE REPORT of JOHN SMEATON, Engineer, upon sundry Matters referred to him by a Minute of the Board of Trustees of annexed Estates, dated 29th January 1770; as also by the Letter of Mr. Secretary Barclay, of 17th July 1771.

The several subjects are as follow:

(Board's Minutes, 29th January 1770.)

Bridge over the River Bewlie.

Do. - - Conon.

Do. - - Altgran.

Harbour or Landing Place at Portleich.

Mills and Watercourse of Miltoun of New Tarbet.

(Mr. Secretary Barclay's Letter.)

Stone Piers at the Ferry of Inverbearie.

HAVING carefully viewed the above subjects in the month of August 1771, I transmitted to the Honourable Board plans, directions, and estimates for constructing the three bridges comprehended in the three first mentioned articles, on the 19th of February last; but being in the course of this business suddenly called away to London upon affairs relative to the Grand Canal, as I then by letter informed the Board, and having been by a succession of pressing affairs occupied ever since, it is only now that I am able fully to acquit myself of the above articles.

What regard to the three first articles I have in a great measure delivered myself upon as above mentioned; it only remains that I assign my reasons for preferring the situations for which these plans are respectively drawn.

Respecting the River Bewlie.—The river at the present ferry is not only much wider and deeper than at the place proposed at Dumballoch, but being much more in the tide's way, would on that account also be more expensive; and furthermore as the river seemed to threaten

threaten to break through the neck of the loop, at the extreme bend of which is the ferry, it might thereby happen that the bridge would become deserted; and if the bridge were originally built upon this neck, the cutting of the neck and forming a dam across the river at the present ferry, with a road upon it of sufficient height to be out of the water's wash, would be in itself a considerable expense. At Dumballoch the river has a fair run, is moderately wide and deep, and has a good gravel bottom, and as I am informed that it will not carry the road much about, I think upon the whole that this place is to be preferred to any that was pointed out to me for the situation of a bridge over the river Bewlie.

The fittest place for a bridge over the river Conon has been by the country in general judged at the place called the Rock. The reason why I did not think this place proper I gave in my letter of 19th of February last, which accompanied the plans and estimates, and which, to save trouble of reference thereto, I here repeat: "That I find the total length of a bridge there (at the Rock) will be greater by almost 50 feet than where I propose it; and that it will require one arch to be built of 114 feet span, and as the water is very deep underneath, it will require so great an expense to center and construct such an arch, besides making good the passage over the remainder of the river, which is almost 200 feet more, that I apprehend it is far more eligible to construct the bridge in the place I have fixed upon, where there is a fair and open run of the river."

"The Rock, as so called, being a kind of concreted gravel, which appears in a degree to wear away by the action of the water, it is in no ways certain that the river may not in part undermine the foundation of so great and necessarily heavy an arch, and which from the depth of the water it will be difficult to guard against by artificial means."

Besides the place I have proposed, viz. at the Boat of Braan, there is also another situation westward, at the Turner's Boat of Braan. This is so nearly equivalent with the former, that the same design would suit either place; but by being further westward, I apprehend it must take travellers further round, the passage at the common ferry over Conon being eastward of all those places.

Respecting the passage of Altgran, there is no choice; there is already a weak timber bridge which may occasionally take over a horse.

PIER or Landing-place at Portleich.

PORTLEICH is situated upon the north west side of the bay of Cromartie, which is in the whole so entirely land-locked, that it cannot at any time be any great sea, such as places adjoining upon the ocean are subject to. The bay of Cromartie may therefore in the whole extent of it be justly considered as a safe harbour; however, being some miles broad, it sometimes happens that there is a greater swell raised within itself than is agreeable to vessels lying upon the ground at low water to deliver or take in a cargo. The shore at Portleich lying upon a very gentle slope, and the tides being rather short, not exceeding 11 feet at common spring tides, it happens that in order to get a very moderate depth of water at high water, it will be necessary to advance the pier or landing place a considerable way from the high water mark in the bay. A pier therefore of the length of 188 yards, will but barely reach from the low water mark at spring tides; so that alongside this pier head, which I propose to be the landing place, there will be about 11 feet water at spring, and about 7 or 7½ feet at neap tides. About 24 yards next the pier head is designed to be of 12 feet broad at top, so as to be convenient for a landing place for vessels to lie on either side, the rest of the pier being only 9 feet broad at top, is considered only as a causeway for making a communication for carriages between the shore and the landing place; but will be very useful in sheltering fishing boats, for the sake of which a few large whinstones are roughly thrown together. The new pier is proposed to take its commencement from a stone that I marked when there, a little to the westward of the present landing-place, and to extend in a direction towards the castle of Cromartie; so that vessels which while unloading want to take the shelter of the pier may lie on either side thereof, according to the wind and season of the year. As the shore is a muddy kind of sand, and a very flat slope, a pier run out in this manner, by intercepting the circulation of the water, may gather mud on each side of it; but to prevent its gathering near the head in the part joining the causeway to the pier head, two arched perforations are left, through which the seas and current acting will be the most likely means of preventing the gathering of mud near the pier head, where the water is most required to be deep. The foundation of the pier is supposed to be laid originally one foot under the surface of the sand, so that being 15 feet in the whole height, it may be allowed to settle one foot more in the sand, and yet remain two feet above the high water of spring tides, which I apprehend where the seas are so moderate as in the bay of Cromartie, will be a sufficient elevation.

In regard to the estimate of this, as well as for the rest of the proposed works, the only thing that I can be certain of is the quantities, for the prices depend so very much upon the kind of workmanship employed, and carriage, that I cannot be at any certainty about them. Where the carriage does not exceed a mile by land or five or six miles by water, I apprehend the prices I have annexed will suit, on a supposition that labour is not dearer in the shire of Ross than in the south of Scotland.

ESTIMATE for building a Pier or Landing-place at Portleich, upon the Bay of Cromartie.

	£.	s.	d.
THE pier head, comprehending 78 feet in length, to be 15 feet broad at bottom, 12 feet top, and 15 feet high from the foundation, at a mean thickness of two feet outside, will contain 6620 cube feet of rough scapped block freestone, which being laid dry, the quarrying, freight or carriage, and building, at 5d per foot	137	18	4
To 340 cube yards of quarry rubble or broken whinstones, for filling the body, winning, freight or carriage, and laying in place, at 1s. 6d. per cube yard	25	10	0
To cramps and lead for confining the corner stone at the termination of the pier head	1	0	0
The pier head or landing place	164	8	4
To continuing the pier or causeway from the landing-place above mentioned to the shore, being 162 yards in length, and 9 feet broad at top, which at the mean thickness of 18 inches, will contain 21,141 cube feet of scapped free stone, at 4½d.	396	7	10
To 1062 cube yards of quarry rubble or broken whinstones for filling the body, at 1s. 6d. per cube yard	81	13	0
To extra work in the two arches	4	0	0
	482	0	10
Sum of the above, being the neat estimate	646	9	2
To contingencies at 10 per cent.	64	12	11
Total	711	2	1

The MILLS and Watercourse to the Mills of Miltown of Newtarbet.

The mills of Miltown of Newtarbet are in very bad repair, and need rebuilding; but so far as I can learn, when in repair are sufficient to answer the purposes; and their method of grinding in that part of the world is in a particular way, which their construction of mills is adapted to answer, I cannot venture to give any new designs, which might require different millwrights and millers to what the country furnishes, to make them succeed, and at last probably to satisfaction: I therefore refer the Board to get their mills rebuilt in the most substantial way that is in practice in the country where they are, as soon as a proper situation can be fixed upon. The matter here, which is most pressing, and about which some advice is the most necessary, is the dam head, by which the water of the river is turned into the watercourse or lead from thence to the mills. The dam head and watercourses, as relative to the situation of the mills, must be looked upon as a very remarkable piece of projection, for after raising a dam head to about three feet, to an extent of 250 feet in length, across a river that in general is not above 50 feet wide, and after conducting the water along the face of the rocks, in an aqueduct built up with fods, which are perpetually failing and tumbling down, it is in a course of about half a mile in which there is a fall of about 20 feet, ultimately conducted to the troughs of the mills, from whence to the bottom of the wheels there is *only about 11 feet of fall* made use of after losing twice that quantity by the road; so that it would seem that the original projector had extended his watercourse upon the river in order to meet with difficulties: had the work been permanent there had been no error, but a loss of so much labour in the first erection; but the misfortune is, that the dam head being only built with loose stones, it is broken by every speat that comes down the river, and as certain tenants are obliged to build it up as often as it comes down, and sometimes obliged to work up to their middles in water, even in winter, it becomes not only a heavy burthen upon them, but a great interruption to doing the business of the country, that is thirled to those mills.

Two ways offer themselves to avoid these inconveniences, one is, by building a new dam head near the place where it now is, and removing the mills; the other, to build a new dam head at a new place, and conducting the water to the place near thereto, that may be more convenient. By reference to the plan made by Mr. David Aitken the surveyor, it appears, that if instead of the dam head, which turns the water into the present

present head, a dam head is erected higher up, and a new lead or watercourse cut on the other side of the river, in the direction that the mills can have a fall into the river there, which he makes to be no less than 18 feet 3 inches, which indeed is more than sufficient for the purpose of the mills, they having now in effect only 11. The objection that occurs to me is as follows: A part of the pleasure-ground, or policy of Balgoun, lies contiguous to this dam's head, and the ground on that side being elevated scarce 18 inches above the level of the water, would be very liable to be overflowed by the pen of the present dam in speats. Were it not for the great length of the dam which takes off the water in a sheet of no less breadth than 250 feet, and generally in the greater speats breaks down. But were this water pent up by a dam, whose length will be no more than 84 feet, according to Mr. Aitken, the water will be confined in so narrow a compass, in proportion to what it is at present, that it would undoubtedly be more liable to overflow the policy above mentioned: whatever damage may happen to the policy by the present dam, it may, as I apprehend, be prescribed for; but in case the situation of the dam is changed, or the dam itself altered, if the laws of Scotland are in such cases part of the laws of England, such new dam cannot be prescribed for, but must be liable to all damages that may arise from it. In order, therefore, that the dam and watercourses may be clearly freed from the possibility of litigation, I observed that there was no kind of necessity to bring the water from the old dam, but that the level would admit of the water's being taken up even below the bridge where the Cromartie estate extends on both sides, and can be conveyed into some part of the present lead before it arrives at the mills, and consequently, that the situation and power of the mills will remain the same as now. The surveyor reports, that from the supposed new dam head to the surface of the water in the mill lead, is a fall of 8 feet 2½ inches; he does not clearly distinguish whether he supposes the dam head raised up to the level of a marked joint of the middle pier of the bridge, which he says is 3 feet ¼ inch higher than the surface of the ground at the place proposed by me for the dam head; but supposing the level taken from the said joint of the pier (as the most unfavourable supposition), if we cast off the 3 feet ¼ inch for the height of the said joint above the said ground, and (if need be) two feet more to bring the dam's crown within the land, there will still remain three feet of descent from the dam head, through the new part of the watercourse into the old one, which in a course of 550 yards is more than sufficient; it therefore follows, that the new dam head need not be raised more than is sufficient to divert the water into the new watercourse, and there appears to be a fall of full four feet to the head of the mill troughs, if the mills were rebuilt, where there seems to have been formerly a walk mill, this four feet might be added to the present fall of 11 feet, and make 15, which would cause the mills to work still more briskly; but

but if the present situation is found more commodious, the fall at the mills may be considerably increased by raising one of the banks some part of its length.

The design for a dam head, that I have given, amounting to 180l., supposes the work to be done in the most substantial manner, and so as to be likely to be permanent; but as it appears to me, that a few flat stones set upon the edge, so as to form a line across the river, might be sufficient to divert the water into the new watercourse, and the work may be done in this way, in case the Board is willing to save a good part of the outlay, by subjecting the work to small derangements by floods.

ESTIMATE for a new Dam Head and Watercourse for the Mills of Miltown of Newtarbet.

	Cubit feet.	£.	s.	d.
To fir timber in bearing piles, plank piles, string piece and cover, containing	209			
To oak and fir timber in the sluice	17			
Timber in the whole, at 4s. per foot, wood and workmanship, and measured neat in place	226	45	4	■
To iron work in the whole		3	0	0
Carpentry total		48	4	0

MASONRY.

To casting foundations		3	0	0
The dam's end wall to be four feet thick, and supposed eight feet high from the foundation, being 96 feet long, will contain	4½			
The sluice walls within and without the clough or sluice, being two feet thick and four feet high from the foundation, and in the whole 70 feet long, will contain, say	1			
Roads of rubble masonry at 5l. 10s.	5½	31	12	6
To allowance at 3d. per foot, face measure, upon the dam's end wall next the water, and on the top to allow for larger stones, capping and rough working the same, 1152 feet		14	■	■
Carry forward		49	0	6

	£.	s.	d.
Brought forward	49	0	6
To freestone scapelled for the surface of the dam, 72 feet long, 19 feet broad over all, and at a medium of 18 inches deep, will contain 2052 cube feet, at 5d.	42	15	0
To 72 yards cube of quarry rubble, or broken whinstones for filling the body and securing the skirt of the dam, at 1s. 6d.	5	8	■
Total of masonry	97	3	6

SPADE-WORK.

To cutting a new aqueduct of five feet bottom, supposed three feet mean depth, with proper slopes, 555 yards running, at 6d.	13	17	6
To banking across the flat from the dam's end to the high ground, being about 27 yards long, 3 feet top, slopes 3 to 1 to be covered with sods, containing 234 cube yards, at 4d.	3	18	0
Total of spade work	17	15	6

ABSTRACT.

Carpentry and iron work	48	4	0
Masonry	97	3	6
Spade-work	17	15	6
Neat estimate	163	3	0
To contingencies, at 10 per cent.	16	6	4
Total	179	9	4

The PIERS, or Landing-places, at the Ferry of Inverbreakie:

On this head I am directed by Mr. Secretary Barclay's letter of 17th of July 1771, "to examine into the state of the above ferry, and consider the propriety and utility of building the pier proposed." The ferry of Inverbreakie is situated upon a narrow part of the bay of Cromartie, somewhat similar to Queensferry upon the firth of Forth, but I believe not half the width of the latter; and as the bay of Cromartie is land-locked on every side, and the tides rise and fall far less than at Queensferry, there is accordingly far less swell and strength of tide; of consequence the ferry of Inverbreakie is by nature attended with fewer inconveniences than Queensferry. The two

two shores at Inverbreakie are upon a moderately quick decline from high water till about the low water of neap tides, after that there is a flat ground on both sides, and for a considerable extent upon the south side, which at low water spring tides lies dry. The consequence is, that whenever the water over the said flats becomes too shallow for the boats to go over them, the ferry is altogether inaccessible to the land except for foot passengers, who may then be carried over the flats on men's backs; and as there is no sort of piers, landing-places, or projecting rock, or any other than a sloping beach, it is not a very commodious ferry for the boating of *horses* at any time, and as to carriages, it seems altogether impracticable, without taking the carriages to pieces. As I went to Miltown of New Tarbet from Inverness by way of Bewlie and Dingwall, and returned by the ferries of Inverbreakie and Kessack to Inverness, I had a kind of practical proof of the utility of these ferries, and beg leave to say, that were the equipment of the ferries of Kessack and Inverbreakie for taking in horses and carriages, as complete as they might be made, no travellers into the eastern parts of the shire of Ross, &c. would go the other road, except those who would rather go 20 miles round than cross any water at all; and even there are two smaller ferries where the inconveniences of embarking and disembarking are almost as great, greater indeed than at Kessack, where there are already tolerable landing-places made by art on each side, though not so good as they might be rendered. The main difficulty therefore at present is at Inverbreakie, where if two stone piers or landing-places were run out from the shore on each side, viz. to the length of 80 yards on the south side, and 100 yards on the north side, this ferry would become practicable for travellers at all times, except for about two hours at the low water of a spring tide. The length of 100 yards on the north side will carry out the pier far enough to enable the boats to work at low water of spring tides; but to do the same on the south side would require that pier to be extended 70 yards further than above proposed. But as those flats seem to be composed of nothing but an oozy kind of sand, I am in hopes that as those piers will in a sensible degree increase the motion of the water over them, there is a chance that the remainder of the flat sand extending beyond the south pier towards the north, may be removed by that increase of the current. It will however very greatly contribute to the utility of the ferry to have the piers carried to the extent above specified; and which may be afterwards extended in case the utility thereof to that part of the kingdom demands it.

ESTIMATE for the Landing-places at the Ferry of Inverbreakie:

	£.	s.	d.
The landing-place being at a medium of six feet high from the foundations, 10 feet broad at bottom, and eight feet at top, will contain of scapelled freestone, at a mean thickness of 18 inches in one yard, 90 feet cube, at 4½d.	-	1	13 9
To 2½ yards of rubble for filling the body, at 1s. 6d.	-	0	4 0
Neat estimate per yard running	-	1	17 9
Ten per cent. for contingencies	-	0	3 9
Total per yard running	-	2	1 6
To 180 yards of pier or landing-places, including both sides of the ferry of Inverbreakie, at 2½s. 1s. 6d.	-	373	10 0

N. B. As there is water-carriage from eminent quarries upon the Cromartie bay, it is likely this work may be contracted for to be done considerably cheaper.

SUTTON BRIDGE.

THE REPORT of JOHN SMEATON, Engineer, upon the Design for a new Bridge over the River Hull, near Sutton.

HAVING inspected the design for a Turning or Swing Bridge, intended to be built over the river Hull near Sutton, and which was exhibited to me by the direction of Messrs. Pool, Watfon, Etherington, and Page, the question being, Whether it will, and in what manner, affect or endanger the flooding of the grounds in Holdernefs, or the navigation of the said river? I am of opinion as follows:

That every bridge may be considered in some degree an impediment to drainage and navigation; yet being a work of public utility, it seems to me, that it cannot be properly objected to where the risk is small and the advantage adequate: respecting drainage, the principal objection that appears to me will be by stopping the ice upon the breaking up of a frost, which all timber bridges built on piles are in some degree apt to do; but the river Hull being a slow running river, will not be so subject to form such obstructions as those that run more rapidly. The bridges from Fulham to Putney, at Kingston, Staines, Maidenhead, and Henley, over the river Thames, those at Beal and Haddlesey over the river Aire, those on the Dutch river over the river Dun, and that at Hull over the river Hull, are so many instances among numberless others of the same kind; and though it sometimes happens, yet it does not ordinarily happen that the ice is stopped thereby.

I see no objection to it in point of navigation, but the trouble of opening it; but I look upon a moveable bridge as a less hindrance to vessels than a fixed one; and, I believe, it was never supported as an objection to the building a bridge, viz. that of the river being navigable. I take it for granted that the width of 22 feet is sufficient for the passage of all vessels that can go there, otherwise it ought to be made so; and, I think, it ought to be made so high that vessels may go under it, in case of the turning part happening to be out of order.

J. SMEATON.

Auffhorpe,
7th Feb. 1772.

WALTON BRIDGE.

THE REPORT of JOHN SMEATON, Engineer, upon the State of Walton Bridge, as it appeared upon a View taken in July 1778.

THIS bridge having been built with the greatest care and circumspection under the care of that eminent artist Mr. Etheridge, and of the very primest timber that could be procured, and which having been finished not many more than 20 years, before it discovered signs of failure, is a monument of the fallibility of all timber constructions where great weights and pressures are concerned.

I found the four middlemost divisions of the great arch supported by four rows of pillars raised upon a scaffold, which were supported by four rows of piles driven into the bed of the river, by which means the great arch appeared sufficiently secured from any further failure that was likely to happen in a short time, and this at the same time furnished the means of examining that part of the bridge which, by the decay of some particular pieces of timber, was in a likely way to have fallen into sudden ruin.

I examined every part of the bridge as carefully as I possibly could, and as nearly as I could come at them; and it appeared to me, that the timber in general was as perfectly sound, and much more hard than it was when the bridge was erected: but in the part where the first symptoms of complaint had shewn themselves, I found some parts of the timber so perfectly rotten and decayed, that it was reduced even lighter and less connected than touchwood, at the same time that the remaining part of the same pieces appeared perfectly sound; and this decay taking place at a critical point where several pieces were assembled, and thereby loosing the geometrical bond and dependence of one part upon another, at the same time that it was in a way inevitably to have brought down the whole of the great arch, it proves that the decay was not owing to the fault of the particular pieces concerned, but to their local situations, of which effect we will now enquire the cause.

The great arch being 130 feet span, and originally not above 27 feet rise above the springers, must, as an arch, be considered as a very flat one, but as there is in the very crown of the arch between 10 and 11 feet in height from the under side of the arch pieces

pieces to the upper side of the hand-rail, this affords a space that in geometrical timber framing would have a very great degree of stiffness independent of its rise as an arch, supposing it not to be overpressed with weight. The main strength therefore of this bridge has been intended by its architect to consist in the strength of the two geometrical frames, making the two sides or external faces of the bridge; between and from which frames he has suspended a floor by strong straps of iron, at every division of the arch; and as he has proposed to cover this floor with a considerable thickness of gravel, which amounted to upwards of 100 tons burthen, over the opening of the great arch, it seems that he has considered that the laying plain beams across from side to side with about nine tons of gravel upon each beam near the middle of the bridge, exclusive of the weight of the timber work, would be so great a burthen as to cause the beams to sag, and totally to fail when they became a little tainted; he has therefore upon the middle of each of these cross beams erected a king post, in the way of the king post of the principals of a roof, and supported these king posts by oblique struts or trusses on each side, footed into the cross beams near the ends, so that these cross beams will resemble the tie beams of a roof, the ends of which, instead of being supported upon a wall, are supported, as has been said, by strong iron straps from the side frames. Now as the rise in the king posts is but small, the side trusses or struts will act very obliquely, and therefore to support the king post, and in consequence the middle of the floor, with its superincumbent weight of gravel, those struts will require to be very firmly footed into the cross beams near the ends, and on this account require to be sunk a good depth into the cross beams, in order to make the footing good: again, near the middle of the bridge, the upper surface of the cross beams will be nearly horizontal, so that any wet that in time of rain percolates through the gravel and makes its way down those oblique struts, to adjacent parts, will run into those footings, and there not being able to escape or suddenly to dry, cannot get out but by a slow evaporation in dry and warm weather; this producing a fermentation, it is easily seen that in those parts so situated a strong tendency to rot must take place, while in those cross beams further from the middle of the arch, their upper surface being more inclined to the horizon, the wet will lodge in a less degree, and consequently they will be less subject to rot. It is also easy to see that some of the timbers similarly situated by accidental circumstances in the cover, being some more, some less liable to take the rot, even though the quality of the timber was all alike. It is further necessary to explain, that besides the intention of strengthening the floor by the trussing abovementioned, in the middle of the bridge a set of ribs are thrown in and abutted one against another, so as to form an arch upon the same principle as the under set of arch timbers do on the outside; but as these ribs so thrown in, cannot be connected with exterior timbers in the manner the outside ones are connected,

and framed with the hand-rail, the middle rib therefore consisting of single timber for three or four bays in the middle of the bridge, till they get more cover, can there afford but a feeble additional support in proportion to the strength of the outside frames. This being premised, it will readily be conceived, what in reality has proved to be the case, that the footing of the strut with the cross beam, being the second from the middle towards the Middlesex side, on the lower beam side of the bridge, being totally rotted through both strut and beam, the end of the beam will cease to be suspended by the iron straps and the weight of the floor, and bed of gravel will become discharged almost immediately upon the middle rib, which being single, though perfectly sound, was sprung in the middle, that is, so far broken as to have lost the greatest part of its strength by large splinters thrown off from under side. The failure of this rib again in part discharged the weight upon the adjacent cross beams, which being also decayed, though not perfectly rotten, must soon have given way in like manner as the former, had not the application been made in due time by the supports under the most weak and decayed parts found it, which giving time for consideration, the question now is, what to do with it?

On examination I found all the truss footings at both ends of the four middle cross beams to be tainted, and some of them considerably decayed, as well as that which was totally so, and caused the immediate failure. As the scaffold did not extend further, I could only judge of the soundness of the adjacent cross beams from viewing them at the distance of 10 feet; and as I found the rest of the timber work in general very little decayed, the parts particularly specified and examined excepted, I am in hopes the taint in the parts I have mentioned has not extended in any great degree much further. It seems therefore to me, that as the greatest part of the structure remains perfectly sound, and the decayed parts capable of being restored, strengthened, and supported at an adequate expense, by means of the scaffold already erected, it would not be for the interest of the proprietor to make at present any material change in the structure, as a repair judiciously conducted may be very well expected to make it last for a term equal to what it has lasted already; and then it will be time to consider whether it may be worth supporting, by throwing another pier into the middle of the river, and thereby making the great arch into two, covered with wood, brick, or stone, as may be then advised.

I look upon it that the present temporary support, exclusive of the deformity it gives to so noble a structure, might be effectual for some years to come, could it be secured against injury from ice floating down the river at the break of a great continued frost; the effects

effects of which, on the arrival of such an event, cannot, I think, be ascertained before hand; there appears, however, a reasonable time for consideration.

When this bridge was undertaken, I apprehend it was the boldest design of the kind that had then been executed, at least in this kingdom; and the principles of its construction carried to a greater extent than had before been experienced. It is not therefore to be considered as wonderful, that after the term of years that has elapsed since its construction, errors have shewn themselves that probably would not have been foreseen by those who now can readily see them, but which in this repair I would as much as possible endeavour to relieve.

The first and greatest error of all was in making so large a middle arch. Had this bridge consisted of three arches more nearly equal, or rather of five arches, and equally well performed, in all probability no material derangement would have happened in the course of a century. The great span of the middle arch made it desirable to make it as flat as possible, otherwise it would have been impracticable to have driven carriages over it;—as it is, though in reality too flat for the span, yet it is still too steep an ascent for loaded carriages, because in their descent they are obliged to drag, and this makes it necessary to keep a cover of gravel much thicker, and consequently much heavier than would otherwise be necessary, and this again, together with the flatness of the arch, so very greatly increases the natural pressure, that overcoming those of the side arches, it makes both the piers lean to landwards, and also lays so great a stress upon the bed timbers which the arch pieces rest upon, that their ends are perfectly sunk into the bed timbers, so that from the whole of the pressure sideways, the crown of the arch is come down above two feet in perpendicular height; and I look upon it, that these are consequences of errors in the first construction, independent of what has happened by the rotting of the timbers; again, the weight of the cover has produced the idea of trussing the cross beams, and this again has brought on the rotting of the beams and struts at their junctures: I would therefore recommend the following mode of repair:

1st, In those cross beams that need shifting, I would recommend to use whole beams without trussing, and rather to fill up the spaces by doubling the beams than the use of struts; the timbers being thus unwounded will be less subject to retain moisture and rot.

2dly, I would remove the gravel totally from above the nine middlemost bays of the middle arch; and therewith by increasing the height and length of the slopes, reduce the

the lateral declivity, and by bringing a greater weight over the side arches, enable them to nearly to counterbalance the lateral pressure of the great arch. This middle space thus laid bare, I would cover with sea coal cinders such as are collected by the dust carts, and sifted near London, for the purpose of burning bricks; and this cover of cinders being gradually reduced to about six inches thick at the crown of the arch, by this means, I think, that near 1000 tons weight may be taken off from the middle of the great arch; for the cinders being much lighter than gravel, and sticking together much more closely, a less thickness is necessary, and by easing the descent, the dragging over the great arch may probably be prevented, or at least rendered less detrimental.

3dly, By way of a general fit of the whole of the great arch, I would advise under all the arch timbers between the radius pieces, to chock in barks of fir, and to tighten each piece separately by oak wedges, and when all are in, to tighten up the whole with lead or copper plates over the joints to keep out the wet, and this I would advise to be done with respect to the middle ribs, or arch pieces, as well as the outsides; all which having fair footings cut into the stone of the pier, above the cordon, will also greatly relieve the pressure of the present arch timbers upon their bed timbers.

J. SMEATON.

London,
30th March 1779.

ESTIMATE for building a brick Superstructure upon the present Piers, with the addition of a new Pier in the middle of the River, for a Bridge over the River Thames at Walton in Surrey.

	£.	s.	d.
To clearing and preparing the foundation for laying down a new pier in the middle of the river, suppose	40	0	0
To constructing a caisson and bottom for the pier to rest on	136	■	■
To the construction of two centers for turning the arches, and removing each of them into a new place	339	8	0
Preparing the foundation, and carpentry, and iron-work	515	17	0

THE PIER.

To case the same with Purbeck asfler will contain 2396 cube feet, which if set in place, at 3s. per foot, will be	359	8	■
The inward case or filling of ditto with grey stock brick, and terras mortar quite solid, will contain 2548 cube feet, which at 13d. per foot	138	0	4
Masonry and brick work	497	8	4

THE ARCHES.

The two great arches, at 2½ brick thick, will contain 227½, say 23 rods of brick work, entirely of grey stock quite solid, in good mortar, at 8½ 15s. per rod,	201	5	■
The two lesser arches, at same thickness, will contain 18 rods of works, at 8½ 15s.	157	10	0
The four new arches	358	15	■
The spandrell walls, to be at a medium two bricks thick, completely faced with grey stock bricks outside, will contain in 270 feet length on each side, in the whole 37 rods of work, which at 8½ per rod	296	0	0
The walling and vaulting in order to fill up the spandrells between the arches and support the gravel road, will contain 42 rods of the best place brick work, at 7½ 7s.	308	14	0
To spandrell walls and vaulting to support the road	604	14	0
To 540 feet running of Portland stone wall capping for the parapets, to be 1½ inches thick, will contain 660 cube feet, which laid on and cramped, at 4s. 6d. per cube foot, will come to	148	10	0
To flagging a walking path on each side with Elland edge flaggs, two feet broad, and 270 feet long, will contain 1080 feet, at 1s.	54	0	0
To 550 loads of gravel to form the road, at 1s.	27	10	0
To capping, paving, and gravelling	230	0	0

AB-

ABSTRACT of the preceding ESTIMATE.

	£.	s.	d.
Preparations for the foundation, caisson, and centers	515	17	0
Masonry and brick work in the pier	497	8	4
The four new arches	358	15	0
The spandrell walls and vaulting, to support the road	604	14	0
To capping, paving, and gravelling	230	0	0
Neat estimate	2206	14	4
To allow for contingent expenses 10 per cent.	220	13	5
Total	2427	7	9

N.B. The above supposes the bottom of the river to be a gravel of sufficient consistence to lay down the pier without piling, ■ the former piers appear to have been, and also those of Westminster Bridge.

No allowance is made for taking down the wooden superstructure, as the value of the timber when taken down, will be much more than the expense.

HARRATON BRIDGE.

ESTIMATE for a Scaffold Bridge on Stone Pillars, at Harraton upon the River Wear.

	£.	s.	d.
To making coffer dams for keeping off the water for the four foundations	116	11	0
To digging and framing the four foundation pits to be filled upon the stone head	60	0	0
To making a horse chain-pump	60	0	0
To works of horses and drivers in drawing the four foundation pits	63	0	0
To clearance for the masonry	299	11	0

MASONRY.

To 1088 cube yards of terras rubble work in the four square foundations to support the pillars, at 9s. per cube yard	486	0	0
To 3100 cube feet of terras work cased with aisler at 6d., to bring the work above low water	77	10	0
To 627 cube yards of aisler building in the superstructure, at 4s.	125	8	0
To 640 cube feet of aisler work in the parapets of the terminating pillars, at 7d.	18	13	4
To lead and iron in cramps for the masonry	20	0	0
	727	11	4

CARPENTERS.

In the two great truss beams,	882		
In the cross beam, standards, &c.	485		
1367 at 2s.	136	14	0

SMITH'S WORK.

To 8½ cwt. in 60 main bolts at 50s. per cwt.	20	12	6
To 5½ do. in spike nails, &c. at 42s. per cwt.	11	11	0
	32	3	6

PLUMBER'S WORK.

To sheet lead to cover the two main truss beams, 28 cwt. at 11. 1s.	29	8	
---	----	---	--

AB.

ABSTRACT.

	£.	s.	d.
Preparing foundations	299	11	0
Masonry	727	11	4
Carpentry	136	14	0
Smith's Work	32	3	6
Plumber's work	29	8	0
Neat estimate	1225	7	10
Add 10 per cent. for contingent expenses	122	10	9
	1347	18	7

Lambton,
26th June 1783.

ESTIMATE of the Stone Arch and additional Pier.

	£.	s.	d.
To sinking and timbering the foundation pit	13	5	0
To drainage of the water	15	0	0
To 270 cube yards of rubble in terras	121	10	0
To 775 cube feet of aisler in terras, at 6d. per foot	19	7	6
To 157 cube yards of aisler building, at 4s.	31	8	6
To 810 cube feet in the arching, at 7d.	23	12	6
To 1152 cube feet in the spandrells and parapets, at 7d.	33	12	0
Neat estimate	257	15	0
To 10 per cent. for contingent expenses	25	15	6
	283	10	6

J. SMEATON.

Lambton,
27th June 1783.

METHOD

METHOD of founding and building the Stonework of Harraton Bridge.
The Method of founding the two Land-breast Pillars of Harraton Bridge upon the Stone Head, as follows:

THE stone head at the north pillar lying but about eight feet, and the south pillar somewhat exceeding twelve feet below low water-mark, I shall confine my remark to the south pillar, because what will do for that will become perfectly easy as to what concerns the north pillar.

The south pillar being considerably within the bank, I would set out the pit about 18 inches or two feet wider on each side, and longer at each end than the intended foundation; and then going down perpendicularly, I would support the sides by framing in the manner of a common square pit or shaft; but as the bearings on the sides would be 30 feet in length, I would not only make the ribs pretty strong (suppose half barks,) but support them with two or three sets of cross-stretchers, and then get out the matter with corves and baskets, till you get down to the stone head, carrying down the frame, and putting in new ribs as often as you find necessary from the looseness of the matter, as you do in sinking a pit.

The stretchers may either be borrowed back or walled in, and the greatest part of the framing may also be borrowed back, the ground tier of ribs excepted, which may also be avoided by driving down boards endways as soon as they will reach the stone head.

The two pillars in the bed of the river I would get down to the stone head, by driving a case or coffer dam of rebated piles down to the stone head; for the deeper pillar which is the south one, the piles would not want driving above 9 feet into the ground before they would come down upon the stone, and the piles being 20 feet in length, would reach above high water mark. These too flat sides when the water was pumped out, would want supporting with cross-stretchers, as described in the foundation pits for the land-breasts.

I would compose each side of this case of whole timbers well shod with iron, to make them enter the stone, if of a soft quality, and thereby get the better footing. The intermediate spaces I would fill up with half timbers rebuted edgewise, and into the main timbers, so as to form in the whole one solid sheet; this would greatly ease the pit of water,

water, that would otherwise be produced, and from the inside of this case to get out the water so as to found upon the stone head.

What will greatly contribute to facilitate all these operations, will be to have pump-machinery quite master of the water, and for this purpose it will be well to have two pumps, one for each end of the pit, but each be worked by the same horse work, so that the water may readily draw away, and each be serviceable if the other is out of order.

The piles composing a case for the south pier will afterwards do for the north, and after all, the timber will be very fit for use.

CONSTRUCTION of the Masonry for Harraton Bridge.

The square foundations, supposed to bring the solid work up to the bed of the river, comprehended in the 1080 cube yards of terras rubble in the estimate, I suppose to be composed chiefly of blocks, flatted and bedded with the hammer, so as to make them lie flat, and being all of a height in the same course, the interspaces may be carefully filled and packed with common rubble work, so as to bring the top of the course to a level: the blocks composing the outside of each course to be straightened and rough jointed with the hammer.

The mortar for this purpose to be thus composed: for every two bushels of unslaked or clod lime, allow one of terras, and three bushels of coarse clean sand, or ditto mixed with fine gravel; a sufficiency of which mortar being allowed as common backing mortar for common rubble work, it will be worth while to use large stuff, and bring it a little together by hammer jointing, to save the mortar.

The 3100 cube feet of terras work cased with aisler, being the whole of the solid of the shaft of the columns from the above ground solid, for four feet in height, which will bring the work above low water; I suppose the average of two feet breadth from the outside to be of aisler, and set in terras mortar; viz. to a bushel of clod lime a bushel of terras, and a bushel of clean coarse sand, well beaten, and used as soon as brought to a proper

proper consistence, the interior part of the rubble work in the same mortar ■ prescribed for the square foundations; so that the use of the internal blocks flatted and bedded as before mentioned, will not only save the backing mortar but render the work stronger.

The rest of the solid of the pillars computed to amount to 627 cube yards, to be built with asfler in the proportion of the last article; only as no terras will be necessary, the terras must be supplied by the addition of an equal quantity of sand, that is, to two bushels of clod lime four bushels of sand.

J. SMEATON.

*Ausborne,
14th November 1783.*

BRIDGE AT CARLTON FERRY.

Mr. SMEATON's Opinion concerning the building of a Bridge over the River Aire at Carlton Ferry.

HAVING considered two designs for a bridge over the river Aire at Carlton Ferry, one being for ■ bridge of stone, and the other for a bridge of wood upon stone piers, both drawn by Mr. John Carr, Architect, I am of opinion that the design for ■ wood bridge being no more than ■ head-way above the level of spring tides, will not be sufficient for ■ vessels under the same in time of freshes; such, as in other respects, allow the river to be in ■ navigable state: but that the design for a stone bridge, the crown of which arch appears to be intended to be elevated above 21 feet above the level of the spring tides, will be sufficient for the purposes of navigation. But that in case the wood bridge before mentioned, is furnished with draw leaves or falls properly constructed to answer the purposes of navigation, then I see no objection to the said design on account of navigation.

J. SMEATON.

*London,
25th April 1774.*

On Mr. CARR's Design for Carlton Bridge.

THE hindrance that an additional stone bridge of any kind must necessarily be to the navigation, I apprehend has been fully considered by the proprietors of the navigation previous to obtaining the act; and as this bridge will, according to the measures stated thereon, afford a sufficiency of head room for the vessels in all extremes of floods, I do not see any material objection thereto that can be removed. But as the arch will be always more or less of it under water, and as much as possible to prevent damage to the arch and to the vessels by striking, and the masts and ropes by rubbing against it, I would advise

advise that the angle which the face of the arch makes with the soffite, be rounded off by a radius of about one foot, quite round from one springer to the other, on both sides of the bridge.

As a considerable part of the present water-way appears to be interrupted by a solid, it seems worthy of consideration by Mr. Carr, whether a dry arch on each side may not tend to the security of the bridge in giving more ample passage to the water; this matter chiefly relates to the proprietor of the bridge; yet if any thing material should happen to the bridge from the want thereof, the navigation may in consequence suffer interruption.

I. SMEATON.

Aufhorpe,
18th January 1775.

MONTROSE BRIDGE.

ESTIMATE of a Bridge according to a Sketch proposed for Crossing the South Esk from the Inch Breck to the Fort Hill at Montrose.

	£.	s.	d.	£.	s.	d.
TO masonry in the bridge, extending from the north abutment towards low water mark, upon an extent of 150 feet from high water mark, at the foot of the brae, towards the main channel, from a computation of particulars				1697	0	0
To nine bays of timber scaffolding, at 45 feet each, extending in length 405 feet, from a computation of particulars, at 233l. each bay				2097	0	0
To the masonry extending from the south end of the said scaffolding to the south shore, if taken at the same price as that in the north (though less work), will be				1697	0	0
				5491	0	0

EXTRA ARTICLES.

To a great piling engine for driving the large bearing piles	150	0	0
To small piling engines, boats, punts, various machines, scaffolding, centers, and utensils	500	0	0
To superintendance, suppose for two years	240	0	0
To incidental and unforeseen expenses	250	0	0
To expenses in temporary scaffolding, and driving the main bearing and fender piles, being 56 in number, at 3l. each	168	0	0
To the contingency of quarry rubble for the purpose of securing the ground about the foundations, where it may be found necessary in the course of the work	38	0	0
	1346	0	0
Total of the bridge	6837	0	0

INCH BRIDGE.

The bridge over the inch burn being of masonry, and taken at the same expense as the north end of the main bridge, will come to	1697	0	0
	8534	0	0

N. B.

N. B. In the above estimation no roads by way of access, nor any thing is computed beyond the termination of the parapets of the wings or retaining walls, no charge by law, interest of money, or damage of grounds for laying and working materials, or quarry leave, nor any remuneration to the engineer in chief.

The main walls are supposed to be of a Craig rubble stone, built in the best manner, in the style of the fronts of the new school. All the building under high water-mark to be done with mortar proper for the salt water: the arches, blocking course, and capping, and such quoins and courses of the foundations as are necessary to be hewn, are estimated of the best Lauriston stone. The timber is all supposed to be of the best Riga or Dantzick fir.

The charge per foot running of the masonry part is 9l. 14s., that of the scaffolding 5l.

TINMOUTH BARRACKS.

To the Honourable Mr. St. John.

Sir,

Newcastle, 22d January 1780.

Mr. WALTON received your letter of the 28th of December last, desiring our opinion upon certain matters therein mentioned, and accompanying a plan of a parcel of ground part of His Grace the Duke of Northumberland's manor of Tinmouth, upon which barracks have been erected, and also a particular and valuation of the said parcel of ground, and the coal supposed to be under the same, proposed to be given in exchange for sundry parcels of land, which His Grace holds by lease from the crown.

We now beg leave to acquaint you, Mr. Smeaton came to this place on Monday the tenth instant, and that we proceeded upon the business the following day, and wrote to the Duke of Northumberland's principal agent William Charlton Esq., and to Mr. French, His Grace's bailiff for the manor of Tinmouth, and several persons whom we thought proper to have the assistance of on our view. We had no answer from Mr. Charlton, either to our joint letter, or to one Mr. Walton wrote to him upon the fifth instant, and Mr. French gave us for answer that he had no directions, but notwithstanding that he would have attended us upon our view, if he had not been under the necessity, (as deputy clerk of the peace for the county of Northumberland) to attend the sessions; so that we were disappointed of any assistance from the Duke of Northumberland's agents.

We proceeded on our view on Wednesday the twelfth instant to the barracks, and made the necessary observations there, to enable us to ground our opinion upon; and as a new survey of the barracks and ground seemed to us necessary, an able surveyor was immediately set to work, not only to make a survey and plan of the ground upon which the barracks are built, but of the buildings also, and of the several high roads, foot paths, &c., which plan you receive herewith; and also one laid down by a smaller scale, taking in Tinmouth Castle, Clifford Fort, &c., accompanied by an estimate of the yearly value of the lands, supposing no buildings to have been made, and of the expense which it is computed the barracks might at first cost, on the foundation of prices paid in this country for work of a similar nature.

Having since given this business all the attention in our power, we sit down to inform you, that we find the ground upon which the barracks are built, with the space on the outside of the buildings, does not amount to more than seven acres and 19 perches, according to the survey made by Mr. Fryer, and we apprehend the difference of two roods and 25 perches arises from the waste of ground by the sliding of the banks into the sea; and that the quantity will continue to diminish, and the sea in the course of years entirely destroy the buildings on that side of the square of the barracks joining on the seashore: under this very material inconvenience, which in our opinion can no way be prevented but at an immoderate expense, it becomes very difficult to ascertain what may be the present worth of the fee-simple and inheritance of the said parcel of ground, with the way-leave or right of passage over the adjoining lands of the Duke to and from the barracks, proposed to be granted therewith: but having maturely considered the subject, we must observe, that the value of lands principally depends upon local situations; and we do not see a better rule or guide than that which other lands of equal quality in the *same situation* are let for; and as we are well informed His Grace's lands adjoining upon the *same* are let at fifty shillings per acre, the same rate at which Mr. Fryer values them, we cannot think the barrack grounds deserve more; so that the annual value thereof upon the quantity now in being, according to Mr. Fryer's survey, will amount to seventeen pounds fifteen shillings, which, at twenty-five years' purchase, will amount to four hundred and forty-five pounds; but considering the Duke of Northumberland is under no obligation to sell, and it must be supposed he sells merely for the accommodation of the Crown, and considering that such accommodation breaks into His Grace's estate, we think the present worth of the fee-simple and inheritance thereof, with the way-leave or right of passage to and from the barracks proposed to be granted, will deserve thirty years' purchase, amounting to five hundred and thirty-four pounds; His Grace reserving to himself the sea banks behind the barracks, and granting a liberty at all times to the servants of the Crown to enter upon and take such methods as they shall think proper for the preservation of the same.

The public highway for carriages from Tinnmouth to Shields, passing very near the barracks on the north side thereof, will be very sufficient to answer every purpose of the barracks, and the foot paths mentioned and described will be very sufficient for every communication between the barracks and Clifford's Fort, as well as the Spanish Battery.

We have endeavoured to inform ourselves whether any, and what damages may be done by the soldiers in the adjacent lands, and from thence and our own observation, we think that damage (if any) must be very inconsiderable; and from the commanding officer

on

on *the*, when we were there upon our view, we were informed not one complaint had been made during the time of his residence.

It is very clear to us, that it will be attended with no inconvenience to His Majesty's service for His Grace the Duke of Northumberland to reserve the banks between the barracks and high water mark, as mentioned in the said particular, there being no appearance of use from those banks to the *sea*, for the purpose of bringing stores by sea to the barracks, or for any other purpose whatever, the banks or cliffs being so steep and rugged as to be very difficult of access; nor could any vessel be brought to the foot, or lie there with safety without digging a harbour, and erecting proper piers for defending the vessels laid therein.

In regard to the coal under the said seven acres and nineteen perches of land, we had that matter under full consideration, and are clearly of opinion, that no calculation of quantity, quality, or *value*, can be made thereof, upon that fair ground which we think ought to determine the value to a purchaser. Conjecture of several seams of valuable coal being within and under the lands before mentioned, cannot justify us to found a calculation upon; we have desired His Grace the Duke of Northumberland's agents to acquaint us if any borings have been made in the lands of His Grace, at or near Tinnmouth, but to this they have given us no answer; and as no judgment can be justly formed without proper trials to be made by boring, we beg leave to be excused from making any estimate with respect to the coal. Our observations with respect to the coal would have ended here, but as we think ourselves obliged to make some remarks on the valuation handed to us, we beg leave to state the following particulars:—The quantity and value, as set down by the Duke of Northumberland's agents, cannot be applied to the value of the coal supposed to be under the barrack lands, as being founded on what His Grace lately agreed for at Tinnmouth Moor, which was then and now is an open working colliery, as no notice is taken of the great expense which attended the winning of it, or of laying waggon ways, building steaths, and other incidental expenses of bringing the coals to market, together with other common expenses attending the vend; we therefore repeat, the circumstance of the Duke's agreement at Tinnmouth Moor cannot apply itself to the value of the coal supposed to be under the barrack grounds, which lies unknown, unascertained, and subject to the expenses before mentioned to obtain it. We have said unknown and unascertained, for at present there is nothing that appears to us to fix the certainty of the existence of any valuable seam or seams of coal under those lands; there may be seams of coals that may be very valuable, for any thing that we can say to the contrary, but whether there are such or not seems to us problematical. The colliery now working by

His

His Grace the Duke of Northumberland on Tinmouth Moor, is at $2\frac{1}{4}$ miles distance, or thereabouts, in a straight line; nor is there any other colliery to our knowledge now worked, according to the nearest line, nearer than half a mile from the barracks, and the seam of coal worked there, according to the general course of the rising of the strata towards the sea, should be either out of or near the surface of the ground at the barracks; but the depth and course of strata may be so varied, even in the last mentioned space of half a mile, by interruptions called dykes, as to leave no more than that kind of probability or prospect, which may be sufficient to induce a land owner or an adventurer to be at the expense of making a trial of the ground by boring; and after that is ascertained with favourable circumstances, yet the expense of making an actual winning, so as to bring the colliery into actual working, and the clear profit thence arising, is in its own nature so uncertain, that the undertaking becomes no other than an adventure, which, if really profitable, by far the greatest part is due to the risque and hazarded capital of the adventurer, and not to the owner of the ground; so that whether the owner himself becomes an adventurer, or any other, the land owner's interest in the coal is no more than what would be given for the privilege of working it, by the general estimation of those who make these adventures their object. Having gone thus far, you will excuse us when we add, that when we know the colliery which is supposed to be under Tinmouth Barracks is won, and in a working state, with the time in which the coal will be turned into money, we will have no difficulty in giving a valuation of the sum it is worth to be purchased, at any given period. At present we have no data to go upon, we have no evidence even of probability from His Grace's agents, and till that kind of evidence is had to reduce the matter to as great a certainty as the nature of the affair will admit of, a doubt must remain with us, and consequently we cannot think it right for His Majesty's service to purchase the supposed property of coal at any rate whatever. But here it may be asked, what will become of the barracks, if His Grace the Duke of Northumberland should find the colliery good, and work away the same? To this we answer, that the working of this colliery seems to us to be at a great distance in point of time, and that though the working of a colliery will occasion the surface of the ground to fall in irregular hollows, and thereby very greatly damage lofty and massy buildings, yet in the present case, we cannot consider the barracks as subject to the same damage, as being low and light buildings, consisting of a ground floor only, and in that respect, in our conception, much on a footing with cottages and pitmen's houses, which are commonly erected on the very ground under which a colliery is working, or to be worked; and as often as such damages happen, reparation is made at a small expense after the ground is settled, and the habitations rendered comfortable again to the occupiers. For these reasons, therefore, with what follows relative to the instability of the barracks, from the sliding banks of the sea shore,

we

we not a doubt but that it will be for His Majesty's service to run the risque of any day, which may be sustained by working the colliery under the barrack grounds.

Having finished what relates to the lands upon which the barracks are built, and the colliery which may be under the same, we proceed to make our observations respecting the condition of the barracks themselves, their stability, propriety, and convenience of situation.

On this head we must observe, that though we cannot look upon ourselves as judges of the propriety of military stations or conveniences, yet we must necessarily take notice, that the banks lying between the barracks and the sea shore, of which His Grace the Duke of Northumberland proposes to keep possession, are of a very considerable perpendicular height, and being composed wholly of a factitious clay, mixed with stones and gravel, and irregularly mixed with a stratum of sand, in wet seasons they become springy; and as the sea continually wears the foot of the cliffs, the banks gradually slide down, and the degree of waste of the banks may be judged of as follows:—

According to the plan accompanying the particular we received from you, a clear space is described between the south line of the barracks and the banks, sufficient to receive the south-east and south-west bastions entire, together with the full breadth of seventy-six feet in the curtain on the south side, agreeably to the rest. At the time of our view we found a considerable part of the south west bastion had slid down into the sea, together with a great part of the original curtain, so that in one place the verge of the broken ground was not twenty feet from the south wall of that side of the barracks; we have therefore no reason to doubt but that in a few years a part of the buildings themselves will slide down the bank, and in time the whole, unless some effectual method be taken for supporting those very irregular inclining banks from the depredations of the sea. We doubt not but that the original state of the ground was according to the plan; it is however now so far changed, that if nothing is done, or the means used by the King's servants for that purpose should prove ineffectual, it becomes, in the next place, a consideration how far those banks can or ought to be supported, which is to be done at the expense of the Crown, and considering this as a matter relative to the good of His Majesty's service, we do not conceive, that with respect to His Majesty's more than any private service, any thing is worth more to preserve than it originally cost to produce, provided it can be reproduced with the same cost, and to the same intent. In this state of the matter, though we do not think it impossible to secure the banks from further depredations of the sea, yet if done in an effectual manner, the expense would be so great that we are very clear it would be far less cost to build

build up the barracks anew as they happen to fail, nay even to build the whole new upon fresh ground, than to secure the banks; and as the soil and site of Tinnmouth Castle are not only the property of the Crown, but in our idea proper for the reception of barracks, there cannot, as we judge, be a doubt of its being eligible to remove them to that situation, in case they cannot be continued where they are at a moderate expense.

And now having concluded our observations, and given our opinion on the several points referred to us, we trust what we have done will be satisfactory; we can however say that we have gone through the whole impartially, and with care and attention; but we cannot dismiss the subject without making this general observation, — that though it appears to be improper to purchase the coal supposed to be under the barrack grounds at any rate whatever, yet we think it would be right to purchase the lands, not only to give the Crown a power of enjoying the barracks, during the continuance of their being useful, but to vest an authority in His Majesty to remove the buildings to the castle, or to let the remains stand as shall be thought expedient. This seems to us to be the best method of settling the business on an equitable footing to the parties, as His Grace will have satisfaction for the property he parts with, and that property will be vested so that it may be made such use of as shall be judged best for His Majesty's service.

We are, Sir,

Your most obedient servants,

NICHOL. WALTON.
J. SMEATON.

P. S. Since forming our ideas and opinions upon which this Letter was written, we have seen Mr. Charleton, but have not received any information from him to induce us to alter the sentiments we have expressed.

To the Honourable John St. John,
Surveyor General of the Crown Lands.

LEEDS INFIRMARY.

TO the Committee of Leeds Infirmary.

Gentlemen,

I HAVE inspected the stone cisterns made at this hospital by the late ——— Craven; I find them nearly of the capacity proposed; but as I understand they never held water from the first, nor do they seem in a capacity of doing so now, or of being made to do so, without taking them all to pieces, and putting them together with the greatest care and firmness, which would of itself be a considerable expense. Each double cistern, when full, is charged with above six tons of water, and relative to this weight they have not only been much too slightly bonded together in their joints with iron, but I apprehend the foundation upon which they have been built has settled under the weight of the whole; for the least settlement or giving in the joints must and will necessarily disunite the cement of whatever kind, and thereby render them leaky. What the nature of the agreement was you best know; if to make them complete to hold water, it was then the undertaker's business to look to the foundation and strength of his bondages: but yet, Gentlemen, if these cisterns can be rendered useful to you, it would seem more eligible so to do, than to return the materials upon the hands of the widow, which, when taken to pieces, will be of little value. I take it for granted you wanted, and still want these cisterns; and had they not been so undertaken to be made of stone, you had ordered them of lead, in which case strong wooden frames of timber would have been wanted to have supported the leaden lining, which frames of timber, though oak, would have been liable to need rebuilding in 20 years, in which case the workmanship upon the lead would have been to renew likewise: had therefore the proposition been how to render these cisterns *durable*, like the rest of the buildings, and which every public building ought to be rendered as much as possible, then you could not have been better advised than to have put together a casing of large stone flags, which the country affords, in order to support the leaden lining, and in this respect these cisterns as they now stand, will completely answer that end; and though in putting them together so as to hold water without such lining, there is work upon them that would have been unnecessary; yet if a reasonable allowance be abated from the first stipulated price for this superfluous work, it will be much less loss to the widow, and much less disadvantageous

to the trust than either the removal of the materials, or an attempt to render the water-tight in the manner they are. According to my estimate they may be completely lined, as they now stand, with lead of 7lb. to the foot, for about or somewhat under 30l.; of which about 8l. will be workmanship, the other will be the neat value of the lead and folder.

According as it has been given in to Widow Craven's estimate was:

	£.	s.	d.
Stones	14	14	0
Cramps and cem	2	5	3
Work	13	2	6
	30	1	9

How far the stones were properly valued at 14l. 14s. I suppose, included) I know not, having never had occasion to purchase any. There are in the whole 20 stones, so that they will come to 14s. 8½d. nearly per stone, which on an average contains about 24 feet superficial each; but as the Committee have agreed to take them at that price, on supposition they were rendered effectual to the purpose, suppose

	£.	s.	d.	£.	s.	d.
Widow Craven paid for the stones	14	14	0			
Cement and cramps	2	5	3			
Work	13	2	6			
	15	7	9			

Half of which is 7 13 10½

which deducted on account of what would have been superfluous, on supposition of the stone frame being made purposely to be lined with lead, then there will remain for cramps, mortar, and work

	7	13	10½
And there will be payable to Widow Craven	22	7	10½

which, in my opinion, is a high valuation of the work for the purpose above mentioned; and there will be 7l. 13s. 10½d. retained in the hands of the Committee toward the workmanship of the lead lining, computed at 8l.; so that the trust will have very little more than the value of the lead and folder to pay for, to make the work effectual in the same manner as if originally intended for lead cisterns in stone casings, which, in my opinion, would have been the complete way of doing it; and, at the same time, the wooden covers, the

the conveyances for bringing in the water, and conduits for carrying it away will be preserved, which would be lost in case the work were totally demolished. That this is an equitable way of considering the matter appears hence: that if the Widow Craven were to line the cistern with lead, she would then undeniably complete the work; and as she would add so much real property to the hospital as the value of the lead, for this she ought to be allowed in addition to the 30l. 1s. 9d., and she would have to pay 8l. for the work instead of allowing 7l. 13s. 9d.

I must observe, that a couple of reservoirs capable of holding between 12 and 13 tons of water, which will be filled many times in the year by rains, will not only be a safety to the hospital, but an acquisition well worth the expense. Rain water is undeniably the best for washing, and though river water is more esteemed for brewing, yet it differs from rain water only in being mixed with a small proportion of hard spring water, of which kind the infirmary having the command by their well, a proper mixture of the two will answer the same as river water for brewing, so that (in very long droughts excepted) the infirmary will always have a command of water within themselves; and, as I apprehend, what water will be wanted during such dry seasons to be brought will be reduced to so small a quantity, that the carriage had better be paid for than go to the expense of any further pump work, reservoirs, or machinery.

J. SMEATON.

Ausborne,
11th Oct. 1776.

P. S. As I have mentioned the want of strength of bondages and foundation as the cause of the failure of the cistern's holding water, it may perhaps be doubted whether they will be sufficient when lined with lead. But, I must observe, that if the amount was the thickness of a piece of post paper, by which the joint was broken, it would be sufficient to destroy the use of holding in the water; but if lined with lead, the lead will comply without breaking; so that considered merely as a casing to support they are sufficiently strong.

to the trust than either the removal of the materials, or an attempt to render them water-tight in the manner they are. According to my estimate they may be completely lined, as they now stand, with lead of 7lb. to the foot, for about or somewhat under 30l.; of which about 8l. will be workmanship, the other will be the neat value of the lead and folder.

According as it has been given in to Widow Craven's estimate was:

	£.	s.	d.
Stones	14	14	0
Cramps and cem	2	5	3
Work	13	2	6
	30	1	9

How far the stones were properly valued at 14l. 14s. I suppose, included) I know not, having never had occasion to purchase any in great quantity. There are in the whole 20 stones, so that they will come to 14s. 8½d. nearly per stone, which on an average contains about 24 feet superficial each; but as the Committee have agreed to take them at that price, on supposition they were rendered effectual to the purpose, suppose

	£.	s.	d.	£.	s.	d.
Widow Craven paid for the stones	-	-	-	14	14	0
Cement and cramps	-	2	5	3		
Work	-	13	2	6		
		15	7	9		

Half of which is 7 13 10½

which deducted on account of what would have been superfluous, on supposition of the stone frame being made purposely to be lined with lead, then there will remain for cramps, mortar, and work

And there will be payable to Widow Craven

which, in my opinion, is a high valuation of the work for the purpose above mentioned; and there will be 7l. 13s. 10½d. retained in the hands of the Committee toward the workmanship of the lead lining, computed at 8l.; so that the trust will have very little more than the value of the lead and folder to pay for, to make the work effectual in the same manner as if originally intended for lead cisterns in stone casings, which, in my opinion, would have been the complete way of doing it; and, at the same time, the wooden covers, the

the conveyances for bringing in the water, and conduits for carrying it away will be preserved, which would be lost in case the work were totally demolished. That this is an equitable way of considering the matter appears hence: that if the Widow Craven were to line the cistern with lead, she would then undeniably complete the work; and as she would add so much real property to the hospital as the value of the lead, for this she ought to be allowed in addition to the 30l. 1s. 9d., and she would have to pay 8l. for the work instead of allowing 7l. 13s. 9d.

I must observe, that a couple of reservoirs capable of holding between 12 and 13 tons of water, which will be filled many times in the year by rains, will not only be a safety to the hospital, but an acquisition well worth the expense. Rain water is undeniably the best for washing, and though river water is more esteemed for brewing, yet it differs from rain water only in being mixed with a small proportion of hard spring water, of which kind the infirmary having the command by their well, a proper mixture of the two will answer the same as river water for brewing, so that (in very long droughts excepted) the infirmary will always have a command of water within themselves; and, as I apprehend, what water will be wanted during such dry seasons to be brought will be reduced to so small a quantity, that the carriage had better be paid for than go to the expense of any further pump work, reservoirs, or machinery.

J. SMEATON.

Author's,
11th Oct. 1776.

P.S. As I have mentioned the want of strength of bondages and foundation as the cause of the failure of the cistern's holding water, it may perhaps be doubted whether they will be sufficient when lined with lead. But, I must observe, that if the amount was the thickness of a piece of post paper, by which the joint was broken, it would be sufficient to destroy the use of holding in the water; but if lined with lead, the lead will comply without breaking; so that considered merely as a casing to support they are sufficiently strong.

EARL OF EGREMONT'S COALS

THE REPORT of JOHN SMEATON Engineer, respecting the Practicability of exporting Coals from the Estates of Bransty, Birkby, and Aspatia, in the County of Cumberland, belonging to the Right Honourable the Earl of Egremont.

HAVING carefully viewed the situation of the estates of Bransty, Birkby, and Aspatia, with respect to the sea, together with the propositions that have been pointed out to me as probable means of carrying and shipping coals from thence respectively, I am of opinion as follows; and, first, respecting

The Estate of Bransty.

It seems here perfectly practicable to carry the coals upon a rail road, across Mr. Ellison's rope-walk from the place where the colliery is expected to be won, to a yard belonging to the said Bransty estate, which has been intended for the deposition of timber, or other merchandise, which is not only adjoining to the public street of Whitehaven, near the arch built by Sir James Lowther, but adjoins upon the waste ground, being the frontage of the sea-shore immediately behind, or north-east of the north pier lately erected as part of, and, as I understand, the boundary of the port of Whitehaven, as described by act of Parliament: coals therefore being brought from the interior parts of the estate across the said rope-walk to the ground contiguous to the sea-shore, as above described, the question is then, Whether it will be more eligible to drop the coals in the yard already described, and from thence cart them through the streets of Whitehaven to the harbour, which is within Sir James Lowther's property; or to build a harbour upon the Bransty estate, contiguous to the said north pier of the harbour of Whitehaven? The proper resolution of this question indeed depends upon a great variety of circumstances; that is to say,

How far it is practicable that a harbour is capable of being erected and kept open upon the Bransty estate, so as to admit of the safety of vessels; and of what burthen; together with the probable cost of erecting the same?

2dly, After knowing the probable cost of erecting a harbour upon the Bransty estate, then comparing the interest of the sum likely to be sunk in effecting this work, with the price of the cartage of coals from the said ground upon the annual vend of coals, that is to be expected to be shipped from the said estate, the difference will appear.

3dly, On supposition, that on this comparison it should appear that the more eligible method is by cartage to the present harbour, it will be a further consideration how far, according to the acts of Parliament now in being relative to the harbour of Whitehaven, Mr. Lowther can entitle himself to, and insure himself of those advantages, in building, and laying on ships, for the reception of His Lordship's coals, the nature of the place in its present state admits of.

4thly, Whether on supposition of the preceding enquiry turning out favourable to His Lordship's views, he will have power of compelling that the street of Whitehaven through which the coals would be carted, should be kept in their present state of repair, on supposition that Sir James Lowther should think proper to cease his cartage through the same avenues?

As an engineer, the first article, comprehending the practicability and expense of erecting a harbour upon the Bransty estate, is the only part of the proposition that properly comes before me, and as this is a necessary foundation for making the other comparisons, to this I shall at present confine myself, leaving the other discussions to be determined where they more properly may, by the gentlemen already employed as coal viewers, to advise upon the winning of the said collieries, and His Lordship's agents in the country.

The north pier of Whitehaven, which has been erected within these few years past as a boundary to the port, appears to me as an unfinished part of a larger and more extensive design; but what this design is, or has been, I had not an opportunity of getting any certain intelligence. From the place of commencement and direction in which it is carried out, it would seem to me, as if Sir James Lowther does intend, or has

has intended, to carry forwards his coals over his archway, and to have shipped from this pier those of his coals that are now carted from the said archway to the quays; were this done, and My Lord Egremont supposed to have an equal right to do the same, his purpose would thereby in whole, or in part, be also served; at present it does not seem sufficiently carried forwards to serve the purpose of either: but taking it as it is, it appears to me to be a very sufficient defence or break-water, so far as it is gone to the south west side of the harbour, that I would propose for Bransty, and which will therefore serve the same purpose to the Bransty harbour as if it had been built with that intent, except what relates to the right of laying of railways, and leading the Bransty coals thereupon, of which point I am uncertain, but of which it would behove My Lord to be fully advised, in case that, upon the whole, a harbour at Bransty is deemed the most eligible.

The actual laying out a harbour requires a more minute consideration than the time I was at Whitehaven would admit; it is sufficient to say, that it appears to me, that a harbour may be made, by running out a pier upon the Bransty estate, from or near to the north west termination of the present north pier of Whitehaven, so as to screen about half a dozen ships at a time from the violence of the south west or western seas, and when any greater number should arrive or be wanted, they can always lie in the port of Whitehaven, either till they can sail after being loaded; or after arrival till a proper birth can be had within the Bransty pier.

I observe that the north pier is carried out from the shore about 160 yards, and extends into eight feet water at a neap tide, which from the flow of the tides on this coast, should make from 14 to 15 feet water at the high water of a spring tide; and which, I apprehend, is as much, or nearly as much, as is generally maintained at the coal quay in the interior part of Whitehaven harbour; and I am of opinion, that by running out a pier upon the Bransty estate of about 120 yards in length, in a proper direction and construction, as much water may be maintained within the same as at the present termination of the north pier.

For this work there can scarcely be a quarry more commodious than that at Jack-a-dandy Hill, or point within the Bransty estate, that is now wrought for supplying the piers of Whitehaven with stone. Having, therefore, attentively considered the situation of the quarry and the work, and having made a careful estimate of the expense of building

in 160 yards running of pier, in this situation it will, according to my estimate, cost 3059l., say 3000l.

Now, if upon the comparisons above mentioned, it shall appear eligible to go into this expense, then I would advise this work to be undertaken, and for which I shall be ready to enter more minutely into the details, and produce the proper working plans: but if not, I cannot advise it to be done. The above expense is, however, independent of the laying of waggon way on the shore, and the making of proper spouts, or hurrys, as they are there called, for putting the coals into the vessels, which may probably swell the above estimate to 4000l. I would not, however, be understood that the building 160 yards of pier, as proposed, will make the very best harbour that can be made upon the place; what I mean is, that it will be sufficient to begin with, and to see how things are likely to answer; and if so, it may be afterwards extended either in length, or by running out a second pier on the north side of Bransty harbour similar to the north pier, or a part made as above mentioned, for Whitehaven; the one or the other to be proceeded with as experience shall direct or shew necessary, after the work first proposed to be erected is put to a full trial. I further looked upon it, that the outworks that have been erected to break off the violence of the south western storms from the harbour of Whitehaven, will be almost of the same advantage to the harbour of Bransty, so that this harbour would answer its end much more advantageously than if the works at Whitehaven had never been erected.

2dly, Respecting the Birkby Estate.

It has been pointed out to me, that by way-leaves through the estate of Mr. Senhouse, the coals of Birkby can be carried to the harbour of Maryport, at the mouth of the river Ellen, and there shipped: upon this proposition the opinion of an engineer is unnecessary; but it is further suggested, that as the estate of Aspatria as well as Birkby is so circumstanced, that this river if made navigable, will be equally useful in carrying down the coals thereof to the harbour of Maryport, and it will also carry the coals arising out of several other estates lying upon the said river; with this idea I have viewed the course of the river Ellen, from a point within the manor of Atterby, where a canal has been proposed to be taken off to go through Aspatria towards the sea, at a place called the Blue Dials; from this point to the harbour of Maryport, according to the course of the river's valley, is full five miles, and as by a level taken by Mr. Johnson, from the

said point of the river Ellen, in the manor of Atterby, to the sea at the Blue Dial, there is a fall of 60 feet, we must account the same descent in the course of the river Ellen, from the said point to the sea at Maryport.

From the said point, taken above the head of the aqueduct of Atterby mill, for about a mile downward, the ground lies very well for a canal out of the bed of the river, but then the valley begins to grow confined, and the borders of the high ground to lie very steep, and grows very embarrassed about the corn mill of Rose Gill, which is a new erected corn mill belonging to Henry Fletcher, Esquire, and seems to have been built at a very considerable expense; from thence downward the river runs very rapid, and in general in a very shallow and narrow bed for about 2½ miles, till we are almost through the Birkby estate; and the bottom of the valley in this space is so narrow, the borders in many places perpendicular rocks, and almost every where so steep and embarrassed that it would be almost impracticable to make the navigation otherwise than in the bed of the river. Below Birkby the valley is more open through the estate of Mr. Senhouse, yet not without embarrassments, arising from the house, and gardens, and mills belonging to this gentleman, and from the aqueduct leading through the same to the iron furnace at Maryport: in short, considering the number of locks that must necessarily be required in a fall of 60 feet, the great rapidity and quantity of water in time of floods, the discharge of which must in many places be provided for, I cannot lay the expense of making the same navigable through the above district at less than 3000l. per mile, that is, for five miles 15,000l., and this exclusive of any compensations to the mills and iron works above mentioned, for loss of water; or to two other mills, though seemingly of much less account; that is, the mill of Atterby and Sir James Lowther's mill, in the lordship of Dereham; for the river Ellen in dry seasons would not be capable of supplying the mills, as well as the navigation, if carried on to any great extent.

Were this river made navigable it would, besides the manors of Birkby and Aspatria, belonging to Lord Egremont, be the means of bringing to market the coals of Mr. Senhouse, as also those of the manors of Dereham and Crosby, belonging to Sir James Lowther and several others; and were the several proprietors of these lordships desirous, aiding, and assisting in bringing the thing to bear, so that there might be no difficulties to remove but those that arise out of the nature of the subject, then it would be a proposition well worthy of attention; but if to the natural expense attending the execution of it, as above mentioned, be added those extra expenses that would attend it, were it to be prosecuted by Lord Egremont upon an adverse principle with respect to the other adjoining

adjoining lords; if carried at all, I am very clearly of opinion the amount would be such as by no means to become an object to Lord Egremont to drive through solely. If this then is the case, it will therefore remain, that should a sea sale colliery be won in Birkby, the coals must go to Maryport by way-leaves, through the estate of Mr. Senhouse, who, if he would not grant way-leaves, would, it must be imagined, oppose navigation also.

It now remains that I give my opinion with respect to

The Estate of Aspatria.

Exclusive of the river Ellen, what has been proposed for the shipping of coals from hence, is to take a canal out of the river Ellen, at some convenient point above the dam-head of Atterby mill, and carrying the canal for about a mile upon a dead level, there to terminate the same, and then to descend by a waggon way the 60 feet that the said point of the river has been found to be above the sea, which occurs in about the space of ¼ of a mile more, to a place on the sea shore in the bottom of Atterby bay, called the Blue Dial. To any part of this proposition I see no natural difficulty; the whole question as to execution, seems to rest upon the procuring of way-leave or licence to make that part of the canal that lies out of the lordship of Aspatria, and the expense of building a harbour at Blue Dial.

In point of original estimation, I would, however, advise that the estimate of the expenses attending the winning of the colliery, be made upon the supposition of a waggon way altogether, from the proposed place of winning to the Blue Dial, without any canal at all.

First, because in order to procure water from the river Ellen, it will be necessary to cut through a property that lies between Aspatria and the river Ellen, as well as through a property that lies between Aspatria and the sea, whereas, if the whole is done by a waggon way, the difficulty of procuring way leave will be confined to one property only.

2dly, Though an ingenious idea of the ready shipping and unshipping of the waggons, containing their loading, from the canal to the waggon ways, and vice versa, was communicated

municated to me by Mr. Johnson, yet it is no ways clear to me, that in so short length of navigation any thing will be saved; whereas, if upon the whole the colliery is likely to bear the expense of winning by a waggon way, and the building of a harbour at Blue Dial, if it shall, after the thing is resolved upon, be found upon entering into minute detail of the particulars better than that any thing can be saved by the execution of a canal, then, by that saving, the thing is out just so much the better: the main point, therefore, that seems to rest upon my opinion, as an engineer, respecting Aspatria, is the practicability and expense of erecting a harbour at the Blue Dial.

The principal disadvantage of this place as to the making of a harbour, is, that as the shore is flat, a pier must be run out to a considerable length before a sufficiency of depth of water can be obtained. Another disadvantage is, that here is no outlet of any river or burn to keep the same clean, which last is indeed a disadvantage common with Whitehaven, but then the sand which is driven coastwise by the sea breeze affects the harbour of Whitehaven as well as Maryport, seems the same sand dispersed, or driven further out to sea; on the other hand, as the seas here are narrow, no considerable swell can come from the northern or north eastern points, nor indeed in the bottom of Atterby bay, where the Blue Dial is situated, do there from the appearance of the shore seem to be very raging seas at any time, so that a single pier, with the turn of an elbow, to screen off the south westerly, westerly, and north westerly winds, will, I think, be sufficient; and being of a proper construction, I apprehend will not be liable to choak up with sand in any obnoxious degree; so that by running out a pier of 300 yards in length, I apprehend that 14 feet water may be gained in spring tides, with a safe birth for four or five ships, and several more of smaller size; this is much about the same depth of water as at Maryport, and as, like Maryport, the flow of the neap tides is considerably less than the spring tides, no vessel of any consequence will be able to stir at neap tides, and which indeed is a good deal the case at Whitehaven: above a week in each spring tide time, there may be expected from 10 to 11 feet water, and upwards, so that vessels not exceeding that draft of water may move every tide, when wind and weather admit, and for six or seven days, about the neap tide time, vessels under 10 feet water only can move; the dead of neap making only about seven feet, which last will yet float vessels of about 50 tons burthen, or about 75 Cumberland tons of coals.

N. B. The largest vessels belonging to Maryport are said to carry about 300 Cumberland tons of coals, that is, they are vessels of about 200 tons burthen, which kind of vessels generally draw about 11 feet water.

Having

Having carefully computed the expense of erecting a harbour at Blue Dial, from an excellent free stone quarry at the distance of about $\frac{3}{4}$ of a mile; the estimate thereof I make to be 5700l.

From those general data, the expediency of the several propositions may be judged of, and the execution of such as shall appear advantageous determined; and when that is done, it will then be proper to review the premises, and to enter more minutely into the detail thereof than this general view, which was comprehended in two days only, would enable me to do.

J. SMEATON.

Auslhorpe,
9th October 1775.

ROSEVEERN AND OWERS LIGHTHOUSES.

To the Master, Wardens, and Assistants of the Honourable Corporation of Trinity House, Deptford Stroud.

My Lords and Gentlemen,

HAVING at your desire, under the conduct of Captain Bromfield, of your brotherhood, surveyed the island of Roseveern, one of the islands of Scilly, and also the Owers Rock off Selsea, in the county of Sussex, with respect to the building a lighthouse on each of these situations, I beg leave to report separately my opinion on each respectively; and first,

Concerning the Island of Roseveern.

We visited this island the 14th of June last, during the time of spring tides. The day being perfectly fine, we landed from a boat without the least difficulty. The whole of the rock composing this island appears to be granite, which, on trial with a pick, I found to be sufficiently workable. The island is of an oval shape, and nearly a flat upon the top. Its length is pretty near east and west, and it gently rises towards the west end, where it is terminated with large granite rocks, naturally piled on each other, higher than any other part. The length of the flat part of the island, including the gentle rise, I measured to 315 feet; and the breadth 132 feet. Without this flat area, the surface declines fast towards the water; and the whole border is composed of large roundish granite rocks, disposed in a sloping form, down to low water, and under it.

The flat area is about seven yards above the half tide-mark, and is about four yards above high water-mark of spring tides. The high rocks at the west end form a kind of breasting; the summit whereof rises near upon 30 feet above the flat area; so that I apprehend the sloping figure, together with the rough breasting described, so far curbs the fury of the western storms that they never break bodily over the flat of the island, which I also infer from this circumstance, that the whole of the flat is covered with a species of soft woolly moss, that, as I apprehend, will not grow where the sea washes very frequently over,

nor does it appear to be attached to the rock sufficiently firm to prevent its being dislodged and dissipated, if a heavy sea were frequently to fall upon it: however, from the formation of these rocks, that in time of storms a heavy spray goes over the whole, and which is also corroborated by there being no grass growing upon them.

From this description it would clearly be a difficult matter to erect a lighthouse upon this island, of any height required, if it were easy to land and unload heavy materials upon it; but as there is no cove or upright breast of rocks so as to afford either shelter or a sufficiency of water for the vessels to keep afloat long together at any time of tide, it is evident that the island can be accessible only by the aid of boats of any size whatever, only in times of the smoothest water. It therefore appears to me, that a sufficiency of time upon the island cannot be got within a moderate number of seasons, without making an establishment upon it; where a number of workmen and an overseer could be lodged, and victualled with provisions, during the summer season. And for this purpose, upon the flat area I have described, there is a sufficiency of room not only for placing the lighthouse but for the erection of cabins for sheltering the workmen, and for stores, and cooking their victuals. And as the whole island consists of granite rock, as already mentioned, the principal part of the stone materials will be found upon the island itself, or its near neighbour, which is also of granite, and can with a small boat be readily visited therefrom.

As a lighthouse may be placed upon this island without being subject to the stroke of the sea, its construction will not need to be of that degree of firmness as if it were exposed to the waves. It therefore may be built sufficiently compact with rubble, or unformed stone, especially if cased with a layer of so moderate a size as to be readily landed, and which may be wrought with granite or moorstone of the best quality in Cornwall, which, from what I have experienced, is from the parish of Constantine near Falmouth; the cement that I have used on former occasions, being of so compact a nature as to unite the whole building into one mass of rock; here being time intervening betwixt the storms for the cement to harden before it is attacked by the wash of the sea.

It may be proper, as a matter on which the whole depends, to suggest the manner in which I would propose to erect the temporary cabins for the lodgment of the workmen. Those I would construct wholly of wood, to be made and fitted together at a convenient harbour on shore; and being carried in vessels at a proper opportunity a sufficient number of them can be landed and set up in a few tides to contain as many workmen as can go on with the erection and completion of the rest. I would propose to make them

them all of fir plank framed cros and cros, so as to compose so many large boxes or chests, when screwed together. I would suppose them about 10 feet square area, and seven or eight feet high; each cabin to have one bed to hold two persons. Two of these to be appropriated to the kitchen and its conveniencies; one having a fire-place of brick, and four more for storehouses, and the overseer. The whole to be joined together, so as to form a street, or narrow lane; the doors and windows to be all next the street and facing each other. I suppose about 12 of these cabins will be sufficient. The whole must be water tight, every where except the doors, and these as light as possible, with air holes to be used at pleasure.

I suppose what I have said will enable the honorable corporation to judge of the practicability of the scheme: when the expediency thereof is determined upon, it will then be in course to make out the working designs; but as very much will depend upon contingency, no draughts that can be made will enable me to form an estimate on proper grounds. However, from the best view I can make of the subject, I cannot judge that this work should be commenced upon a less capital than 6000l., exclusive of the furniture and machinery required for exhibiting a light therein.

Concerning the Erection of a Lighthouse upon the Owers.

The Owers appears to be a hard sunken rock, of considerable extent in the east and west direction; the shallowest water being near the east end, whence it very gently and gradually deepens towards the west.

On Saturday the 26th of June, we rowed in a boat from the floating light; and upon the eastern part had soundings upon an extensive surface at seven feet, and much more regular than could have been expected. In some places, more towards the eastern end, we had six feet and under; but those places seemed more irregular. The wind was fresh at west, and obliged us to depart rather before the computed time of low water: and as this was the day of full moon, and consequently the spring ebbs to be expected somewhat lower, we determined to take another trial, if those springs offered it: and the next day,

Sunday the 27th June, proving very fine, the wind moderate and at N. W. we took another trial, and in a six-oared row-boat went directly over the rock. We had pretty extensive soundings at six feet, some places $5\frac{1}{2}$, and some of 5 feet; but the shallowest ground seemed the most irregular. I don't look upon any of these soundings to have been

been made at so low an ebb as sometimes happens, so that I have no doubt of the truth. It has been reported to us, that a person has stood upon the bottom in a pair of fisherman's boots; but as these times can happen but seldom, I must lay it down, that a middling spring does not give a less depth than 7 feet water; and that to allow sufficient time for tides, we must suppose the rock to be laid in seven feet water at the least. The breadth of the rock in the north and south direction could not well be ascertained for want of fixed marks: I suppose it where we took our soundings to be 100 yards. It seems somewhat narrow near the eastern end, where the least soundings are, but there is not a doubt but that there is an ample sufficiency of room for the base of any lighthouse building.

In time of great storms the shallowness of the water will undoubtedly occasion a great surf to break upon the shore at some time of tide; in consequence, I cannot apprehend that stones of any size that it is practicable to bring and deposit here, will lie quietly without being subject to be removed, unless they are firmly detained in their places. I look upon it as practicable to bring hither and retain such stones as may be expected to lie; and consequently, stone after stone being laid and others upon them, till a regular platform of stone can be formed of regular masonry, above common low water-mark, the building can then be proceeded with upon principles and in methods that have already been put in practice.

There will however occur great natural difficulties to the proceeding with this work, especially in its early stages. Here is too much water at all times to see to do the business in any current method, and here is too little water to float vessels of any burthen, to bring and deliver their materials in size and in quantity: for as they must necessarily be of a flat construction, and must not thump the bottom in a troubled sea, the tonnage of stone that can be expected to be carried out in one cargo cannot be any great matter.

The distance of the Owers from the land, supposed to be at least eight miles, and without any good harbour or quay to retreat to, must considerably add to the difficulty: and the many fruitless voyages that must necessarily occur in pursuing a work in which nothing can be attempted but in the calmest weather, will inevitably render the establishment of a foundation (till it is got above low water) both tedious and expensive. However, to shew that it is a work within the bounds of practicability, I will now take the liberty briefly to suggest to this honourable Board the method in which I would propose to proceed.

Besides

Besides constructing proper vessels, I would, in the first place, construct a diving bell, or rather diving chest, such as was made use of about two years since at Ramsgate harbour, by means whereof large stones that interrupted the clearing a foundation, were got up in 12 feet water, and which it was found practicable to use at a much greater depth had it been necessary. With this apparatus it is very practicable to drill holes in the rock; and, in the first place, to establish a center pin which may be afterwards found, by putting a small buoy upon it; and to which the craft may be occasionally moored while employed there. At a competent distance from this center it is equally practicable to drill any number of holes at pleasure, so as to form a circle, as regular as it could be done upon the plain ground, into which strong iron spindles or pins, being driven to stand up (suppose a foot) above the surface of the rock; large stones of six or eight tons let down within this circular area will be detained from slipping without it till the outward circle of pins is filled with stones of this size, which may be roughly hewn, but so ■ somewhat nearly to fit each other; lastly, the internal area within the circle of stones, being chocked in with large rough blocks, put down promiscuously, will establish a basement course, that, as I apprehend, will sustain a winter's storm, without material derangement.

The upper side of the stones of the outward circle can in their formation have such indentures cut in them, as shall retain in their places another circle of stones laid upon them, on the same principle as the first course is retained by the iron pins. The interior part of this course being also chocked in with rough blocks, these two courses, which may bring the work a foot above low water, and can be further steadied and bonded with iron cramps, I expect will prove sufficient to sustain another winter.

In this situation the work may be brought to a level, the interstices rammed full, and prepared for laying on a cap course in water mortar, begun solid from the middle, and dove-tailed together in the same manner as the Edystone lighthouse is. This solid course being all united as one stone, will, both by its weight and connection, firmly bond together the whole of the under courses, so that nothing can get out of place, though the iron spindles, or steady pins, were entirely to waste and decay with rust.

After this is done a superstructure may be raised upon this compound base on the same principles, and in a similar manner with that of the Edystone.

A work of this kind is still less ■ subject of computation, in regard to expence, than that proposed at Roseveern. It will, indeed, very much depend upon good or bad luck of seasons and circumstances; but I think it ought not to be begun upon a less capital than 20,000l.

I remain with the utmost respect
to this Honourable Corporation,
their most obliged servant,
J. SMEATON.

Grays Inn,
22d July 1790.

COAL MEASURES.

AN ACCOUNT of the Measures of Coals at Newcastle and London, and of the customary Measures in the Parish of Whitkirk, and the adjacent Parishes.

THE Newcastle chaldron, by which coals are delivered to the ships, is fixed by act of Parliament to be 53 hundred weight; and by the stated proportions used at the custom-house, &c., eight chaldrons Newcastle, are to make out 15 chaldrons London measure: the weight of the London chaldron will therefore be 20 cwt. 1 qr. 2 lbs.; and the vats by which coals are measured at London by ~~the~~ are, are, or should be contrived, of such dimensions as to answer the above quantity.

The business of Newcastle in the coal way, not only in regard to the delivery of coals for home consumption but for the collieries, is not done by weight but by measure; the foundation whereof is the coal bowl, which consists of 36 corn gallons Winchester measure strided; a vessel therefore of the capacity of 36 corn gallons corn measure, contains the measure of a coal bowl, and the coals are measured therein by filling them level with the top.

The specific gravity of clean coals (that is, when free from stony or brassy matter, which is heavier) does not greatly differ; so that at a medium it is found and computed that 21 bowls will make a chaldron of 53 cwt., and hence it will follow that the coal bowl will be 276 lbs. neat weight, that is, 2 cwt. 1 qr. 24 lbs., and each of these bowls is a fodder, which is looked upon to be a full load for a two-horse cart, and a fodder is in general estimation looked upon to be two-thirds of a good three-horse cart load (which is not however the mode of carriage of that country, they generally carrying by fodders); 12 bowls will therefore weigh 29 cwt. 2 qrs. 8 lbs., exceeding the London chaldron by 1 cwt. 1 qr. 6 lbs.

Mr. Smeaton has remembered the collieries of Whitkirk parish and the neighbourhood above 45 years; he always understood, that when the owners of a colliery had a mind to recommend their coals to sale, they did it by giving good measure; that is, by giving somewhat more than the usual quantity by making their corves larger, or upheaping

them as much as possible, and when established, and having a greater sale than they could readily supply, they then were apt to shorten their measure; that is, to make the corves less or upheap them less than usual. Mr. Smeaton never heard nor could learn any stated dimensions for a corf; but he always understood that a corf of coals was, or ought to be a good horse load: so that in winter when the roads were but indifferent, the neighbouring farmers seldom carried above 10 corves at once, and sometimes not so much. In Mr. Smeaton's memory coals, as well as all other goods, were in a much greater proportion carried upon horses' backs than they have been within the course of the last 20 years. The stated weight of a horse pack is 18 stone, that is, (eight stone to the hundred) equal to 2 cwt. 1 qr., and this being understood to be the weight of a corf of coals, a dozen at this rate will weigh 27 cwt., that is, 1 cwt. 1 qr. 24 lbs. less than the London chaldron; and in confirmation that the corf of coals is not less than the horse pack weight, about eight years since, Mr. Smeaton being upon some experiments on the subject, weighed six corves of coals, brought home in his own cart from Walton, which were not quite but yet not much short of half the weight of a London chaldron, which made him conclude at that time, that the Halton dozen, and the London chaldron, were nearly the same thing.

From the near coincidence of the dozen of coals consisting of 12 horse pack weight, the London chaldron, and 12 Newcastle coal bowls, he is inclined to think they have all originated from the same thing; videlicet, the coal bowl of Newcastle, which itself has been adapted to the weight they found it practicable to carry on horses' backs, there being few, if any, wheel carriages in England at that time; and therefore before the invention of the Newcastle rail or waggon roads, all the coals that were carried down to the ships must have been conveyed on horses' backs, and though the whole coal trade of that country must have been only a trifle in proportion to modern times, yet the whole of the trade being carried in this way, it must have been very considerable as applicable to horse labour; we may therefore well expect, that in contracting for the carriage of coals to the shipping, it must have been of great consequence in those times to have the quantity ascertained that each horse could and was expected to carry. Accordingly the bowl for wheat, and other grain, in that country being most generally 4 Winchester bushels of eight corn gallons each, that is, 32 gallons; it has been found on repeated trials that a horse was capable of carrying somewhat more than this bowl of coals, and therefore that instead of carrying four eight-gallon bushels, it has been universally agreed that it should consist of nine gallons, and in consequence the coal bowl of 36 gallons, has ever since proved an invariable measure at Newcastle.

He is further inclined to think that originally they sent away three foddors, or bowls, to London for a Newcastle chaldron (as it still continues for home consumption) which at London was sold for two chaldrons, of 12 bowls each; but that as the demand for coals increased, they gradually shortened their measure both at Newcastle and London, and this abuse and uncertainty increasing called for the interposition of the legislature, when, having after a course of years fought the grounds upon which this trade had originally commenced, they settled it as well as they could to what they found a medium at that time, ordering the Newcastle chaldron, not to be a measure, but a weight of 53 cwt.

He has never heard it doubted but that the first collieries in England were opened at Newcastle, from whence they would naturally seek instruction in opening and working collieries in other parts of the kingdom, finding that a bowl of coals was drawn at a time, which then would be most convenient, as being a proper measure for putting upon a horse, the imitators would naturally do the same thing for the same reason; and as in the manufacturing part of the West Riding of Yorkshire, the necessity of a considerable quantity of horse carriage would subsist as far back as the first getting of coals at Newcastle (some time, if he recollects his information right, after the year 1200), the load of coals and the horse pack would easily be substituted for one another, and indeed without supposing the dimensions of a bowl corf to be brought from Newcastle, the reason of the thing, that is, the natural ability of horses to carry burthens, would bring the matter somewhat near, there being only 24 lbs. difference between the pack weight of the West Riding, and the coal bowl of Newcastle, the latter being as before stated 24 lbs. heavier.

Since the invention of the coal waggon roads and other carriages, as well as powerful machines, or gins for drawing coals from great depths, it has been found convenient to draw more than a bowl at once, and it is now in common practice to draw a 20-peck corf, that is, 2½ bowls at a time, ½ of a coal bowl being denominated a coal peck; and since the laying of waggon ways in Yorkshire (the first of which is in Mr. Smeaton's memory), to carry coals to the navigable rivers, they have delivered as many as they can carry in a waggon for a dozen, or chaldron, now amounting to about from 40 to 45 cwt., taking pay for the coals in proportion; but first calculated with intent to avoid the payment of the river's toll, which used to be taken by the chaldron or dozen before the last act of Parliament.

J. SMEATON.

Auslhorpe,
27th January 1779.

N. B.

N. B. The act now passing for Mr. Brandling serving the town of Leeds will, as by agreement, probably fix the weight or measure of the chaldron or dozen at Leeds; but Mr. S. has not yet heard what it is.

To Lady Irwin

Mr. Smeaton sends his most respectful compliments to Lady Irwin, and inclosed herewith begs leave to present her with an account he is able to give of the weights and measures used in the coal trade. ■ they have come to his knowledge.

Auslhorpe,
27th January 1779.

From Lady Irwin.

Lady Irwin is more obliged to Mr. Smeaton for the paper than she can express, and can't, without being infinitely shamed, reflect upon the trouble so very just a state of ■ intricate and ■ ■ ■ ■ ■ must have given him; begs leave to return him her most grateful thanks, accompanied by every good wish for himself and family.

Wednesday Evening.

POZZELANA

POZZELANA MORTAR.

DIRECTIONS for preparing, making, and using Pozzelana Mortar, by
JOHN SMEATON, Engineer.

THE first thing that should be done, is to sift it through a coarse wire sieve, separating what will pass through the sieve from what will not, and then to sift what has passed through the first sieve through one of a finer sort. A wire sieve having about 7 or 8 meshes per inch running, will be of sufficient fineness, and all that will pass the second sieve will be fit for use, what will not pass the second sieve must be reserved for grinding, and what would not pass the first sieve must be broken to a size conformable to what would not pass the second, and then all ground together; but in breaking the large that would not pass the first sieve, it will be proper to pick out a kind of grey stony matter, as well as other heterogeneous substances that get accidentally mixed therewith; and which will readily discover themselves from the true pozzelana, and which have no cementing quality, and render it more difficult to grind. The true pozzelana is of a dark brown or dirty red colour, and the larger pieces being broken will readily discover themselves, especially with an ordinary magnifying glass, to be of a spongy substance with innumerable little cavities like a cinder, and not much harder.

That part of it requiring grinding must first be got perfectly dry, either by the sun or by a drying kiln, otherwise it is apt to clog the mill stones, and it is done by far the most completely by grinding it upon a pair of corn mill stones, which will at one operation reduce it to a proper fineness without need of further sifting; French stones answer the purpose best, for though it may be done by other kinds of mill stones, yet being mixed with flinty matter, which cannot readily be picked out, no other kind of stones will stand the service, if wanted in any considerable quantity. The millers however are not very desirous of meddling with it, on account of its spoiling the colour of their stones. I have therefore in the larger kind of works that I have been concerned in, found it worth while to construct a mill on purpose, to go by water, wind, or horse, according to convenience.

In making mortar of it, it must be mixed with lime in much the same manner and proportion that terras mortar is made; it must be observed that the better and stronger the lime is, the better and stronger the cement will be, but like terras it may be used with
any

any lime, and in making comparative trials with terras, the same sort of lime should be used with both.

The best kind of lime for water works that I know of, is from Watchet in Somersetshire, Abertaw in South Wales, and Barrow in Lancashire, and the strongest composition I know is made by an equal quantity of lime, struck measure in the dry powder, after being flaked and sifted, and of pozzelana ground and prepared as above, and if put together with as little water as may be, and beaten till it comes to a tough consistence like paste, it then may be immediately used; but if suffered to set, and it be afterwards beaten up a second time to a considerable degree of toughness as before, using a little moisture, if necessary, it will set harder but not so quick.

This composition is of excellent use in jointing the stones that form the lodgement for the heels of dock gates and sluices, with their thresholds, &c. when of stone.

A second kind of mortar is made by using the same proportion of ingredients as terras mortar, that is, two measures of lime to one of pozzelana beaten up in the same manner, and which if used with common lime, will fully answer for the faces of walls either stone or brick that are exposed to water, either continually or subject to be wet and dry, in which last case the pozzelana greatly exceeds the terras, as also in its lying quiet in the joints as the trowel has left them, without growing as terras does.

As a piece of œconomy, I have found that if the mortar last mentioned is beaten up with a quantity of good sharp sand, it no ways impairs its durability, and increases the quantity. The quantity of sand to be added depends upon the quality of the lime, and is thus determined: if to the pozzelana considered as mortar, you add as much real sand as will make out the whole quantity, such as an experienced workman would allow to his lime to make good common mortar, this will shew the quantity to be added, that is, may be originally beaten up together; thus, if the lime is of such quality as to take two measures of sand to one of lime, then one measure of pozzelana and three measures of sand will satisfy two measures of lime.

The compositions above mentioned are seldom used further than for 6 inches within the face of the stone, or at most, for setting the stones and the bricks forming the face of the work, while the backing is wholly done with common mortar, and which under water never comes to the hardness and consistence of stone, or forms that bond of union which would arise from a stony hardness; I have therefore found it preferable, where
poz-

pozzelana can be had in plenty, to allow one bushel of pozzelana to eight bushels of the lime composing the mortar for backing.

The first composition will assuredly acquire the hardness of stone under water, and in 12 months will be as hard as Portland.

The hardening of the second and third depends greatly upon the quality of the lime, as also that of the fourth, yet there is scarcely any lime with which the materials well beaten up, in the proportion specified, will not acquire a very competent degree of hardness under water.

J. SMEATON.

Austhorpe,
23d September 1775.

I N D E X.

- A.
- A**BERDEEN harbour, iii. 38.
bridge and mills, 51.
Aberthaw lime, recommended for water cements, iii. 415.
Adling fleet level, i. 199.
Aire, river, drainage of some lands contiguous to, ii. 146.
—, navigation, ii. 131. 151.
Aire and Calder navigation, means of improving, ii. 131.
Allgran bridge, iii. 359. 360.
Anchors of cast iron, i. 409.
Aspatria estate, report respecting the coals of, iii. 396.
St. Aubin, harbour, iii. 211.
Ayr harbour, iii. 151.
- B.
- Bainbridge*, Captain, scheme of a canal for the Tyne navigation, ii. 238.
Banff bridge, iii. 349.
Barrow lime, recommended for water cements, iii. 415.
Berwick bridge, iii. 345.
Bewlie river, bridge over at Dumballoch, iii. 355. 360.
Birch, Mr., water engine, description of, i. 208.
Remarks on, by Mr. Smeaton, 211.
Birkby estate, report respecting the coals of, iii. 396. 399.
Birmingham canal, ii. 189.
Bocking fulling mill, ii. 413.
Boring mill for cylinders at Caron, i. 376.
Braan bridge, iii. 357. 360.
Branfly estate, report respecting the coals of, iii. 396.
Bridlington pier, iii. 178.
Brindley, Mr. J. project of a canal from Wilden ferry to King's Bromley, &c. i. 13.
Brindley, Yeoman and Golbourne's report respecting the Forth and Clyde navigation, answer of Mr. Smeaton to, ii. 98.
Bristol bridge, i. 99. Harbour and canal, 218.
Bucket, new, for fire engines, i. 236.
Bude haven canal, ii. 213.
Bussey mill, its power of grinding, i. 140.
- C.
- Calder* river, estimate for conducting the navigation of, to Dewsbury, Low Ford, i. 20.
Calder navigation, ii. 125. 131. 141.
Call, Mr., scheme of a canal from Bude haven to the Tamar, ii. 224. 226.
Callstock navigation, ii. 213.
Carlisle queries, ii. 319.
Carlton bridge, iii. 383.
Carr, Mr., his design for Carlton bridge, iii. 383.
Carron furnace, i. 359.
Catheart, Lord, letter respecting the river Devon navigation, i. 141. Queries respecting the same, 151. 166. 169. Queries of, relative to the navigation of the Forth, 147. Answer to, 149. Queries of, respecting the Forth and Clyde navigation, ii. 56. Answered by Mr. Smeaton, 58.
Cement for water work, iii. 414.
Chaldron, its weight and measure, iii. 410.
Chase water engine, ii. 347.
Chelmer river, navigation, i. 36.
Chelmsford navigation, i. 36.
Chimney wind-mill, ii. 396.
Christchurch harbour, i. 192.
Civil engineers, society of, i. preface vii.
Clay mill at Carron, i. 382.
Coal measures, at Newcastle and London, iii. 410.
Coals, drawing by horses and by engines considered, ii. 375.
Colemore, Mr., queries relative to the Birmingham canal, with Mr. Smeaton's answers, ii. 189.
Coldstream bridge, iii. 235.
Coln river, i. 319.
Conon river, bridge over at Braan, iii. 357. 360.
Coquett dam, ii. 324.
Corn mill to be worked by a fire engine, ii. 378.
Cronstadt engine, ii. 378.
- D.
- Dalderse* lock, i. 407.
Dalry mills, ii. 419.
Dam for Carron Works at Dun Pace, i. 379.
— for the river Coquett, ii. 324. For Lumley Castle, 333.
Devon river navigation, i. 141. 154. 167. 169.
3 H *Diving*

Diving machine, design of, for repairing the under-washed piers at Hexham bridge, iii. 279.
 Dixon, Mrs., letter of, respecting Mr. Smeaton, p. xxv.
 Donkin, Mr., letters to respecting Hexham bridge, iii. 267, &c.
 Dover harbour, iii. 134.
 Doverain river, bridge over near Banff, iii. 249.
 Downs, account of the first attempts to improve harbour in, iii. 76.
 Driffeld Beck canal, i. 207.
 Dublin grand canal, ii. 247.
 Dumfries, questions by the Town Council of, i. 1. Answers to, 2.
 Dumballock bridge, iii. 355—360.
 Dunbar harbour, iii. 57.
 Dumbarton bridge, i. 339.
 Dundee harbour, iii. 54.
 Duni Pace dam, i. 379.
 Dunkirk sluice, ii. 20.

E.

Edinburgh bridge, iii. 218.
 ——— Water service, iii. 228.
 Edwards, Mr. L., report respecting the river Witham navigation, i. 26.
 Eddyvean, Mr., machines for navigating canals, ii. 213.
 Egmont, Earl, description of his portable fire engine, i. 223.
 Egremont, Lord, coals, iii. 396.
 Elstobb, Mr. pamphlet on Lynn harbour, iii. 3, 12.
 Errington, Mr., letter to, respecting Hexham bridge, iii. 293. Paper delivered by, to the magistrates of Northumberland, 320. Dissertation on the hardship of his case respecting Hexham bridge, 336.
 Ewell and Kingston canal, ii. 230.
 Eymouth harbour, i. 302.

F.

Fenton drainage, i. 6.
 Fire engine, portable, description of, i. 223. New bucket for, 236.
 Flint mill at Leeds, ii. 415.
 Foreman, Mr., letter of, respecting Coldstream bridge, iii. 235.
 Forth, the navigation of, i. 147.
 Forth and Clyde canal, ii. 31. Comparison of, with the canal of Languedoc, 52. Review of some matters relative to, 98. Plan for carrying on the works of, 142.
 Fosdyke navigation, i. 55, 74.
 Fulling mill at Bocking, ii. 413.

G.

Gascoigne, Mr., examination of his proposal for raising water out of ships, i. 215.

Gasconale's apparatus for boring at Carron, i. 394.
 Gatehead Park engine, ii. 362.
 Glasgow bridge, i. 333.
 Gosport waterworks, ii. 381.
 Graves, Capt., proposition for embanking a tract of mud on the river Thanks, ii. 323.
 Grindstones mill, ii. 412.
 Grundy, Mr. J., report respecting Fosdyke navigation, i. 55. Holdernefs levels, ib. 88. Project of a canal from Tetney haven to Lowth, ib. 22. Report respecting the river Witham, 26.
 Gun, at the New River head, ii. 164, 168.
 Gunn, Mr., report of, respecting Perth bridge, i. 164. Directions to, for completing Port Patrick harbour, iii. 71.

H.

Hallam waterworks, i. 7.
 Harrison lock, i. 20.
 ——— bridge, iii. 378.
 Hatfield Chace drainage, i. 115. ii. 299.
 St. Helliers harbour, iii. 206.
 Helvest, sluice at, iii. 145.
 Hertford, navigation to, ii. 155.
 Herwick bridge, ii. 185.
 Hexham bridge, iii. 267.
 Holdernefs levels drainage, i. 88.
 Holmes Carr drainage, i. 39.
 Home, Lord, letters to, respecting Coldstream bridge, iii. 242, 244.
 Hotham cars, i. 234.
 Hubbert's mill stream, i. 245.
 Hull quays, iii. 155. Dock, 163.

I & J.

Inverbreakie piers, iii. 360, 367.
 Irwin, Lady, letter to and from, iii. 413.
 Iwer river, i. 319.
 St. Ives harbour, i. 295.
 Jersey harbours, iii. 206.
 Jessop, Mr., plan for the Aire navigation, ii. 151. Scheme for the Tyrone canal, ii. 278.

K.

Kanquarry canal, ii. 240.
 Kew Gardens engine, i. 12.
 Kilnburst forge, ii. 424.
 King's Bromley canal, i. 13.
 Kingston and Ewell canal, ii. 230.
 Kinnaird engine, ii. 334.
 Kinnoul, Earl of, lands, report concerning the defence of, i. 137.
 Knightsbridge drain, ii. 316.
 Knottingly lock, ii. 242.

Knouch bridge mill, i. 313.

L.

Languedoc, Canal of, ii. 253. Compared with that of the Forth and Clyde, ii. 53. Account of the tunnel in, 60.
 Lea navigation, i. 282 284. 287. 290. ii. 154.
 Lead, Hill's, works, ii. 402.
 Lecch, Mr., scheme of a canal from Bude haven to the Tamar, ii. 230, 235.
 Leeds, navigation to, ii. 131.
 ——— Infirmary, report respecting the cisterns belonging to, ii. 393.
 Lewes Laughton level drainage, i. 340.
 Linton dam, i. 310.
 Litchfield canal, i. 13.
 London bridge, and London bridge waterworks, papers respecting, ii. 1.
 Long Benton engine, ii. 435.
 Longbridge canal, i. 13.
 Lowth navigation, i. 22.
 Lumley castle, fishing dam for, ii. 333.
 ——— Colliery engine, ii. 346.
 Lynn harbour, iii. 1.

M.

Mackell, Mr., instructions to, relative to the Forth and Clyde canal, ii. 71.
 Malden navigation, i. 36.
 Market Weighton, 234.
 Maxwell, Mr. Robt., questions respecting the river Nith, i. 5.
 Memorial by Mr. Smeaton respecting Hexham bridge, iii. 290.
 Milford haven, its character as a harbour, i. 269. note.
 Mill for grindstones, ii. 412.
 Mills, list of, built by Mr. Smeaton, ii. 439.
 Miltoun mills, &c. iii. 360, 364.
 Millerton Sas drain, i. 130.
 Montrose bridge, iii. 385.
 Mortar, for water work, ii. 331. iii. 414.
 Mufkham water road, i. 327.
 Mylne, Mr., report respecting Hexham bridge, iii. 296. His second report, 322. Observations on them by Mr. Smeaton, 324.

N.

New river works, ii. 164.
 Newark water road, i. 327.
 Newcastle on Tyne bridge, iii. 252.
 Newcastle-under-line canal, i. 13.
 Nichols, Mr., instructions to, respecting London bridge water wheel, ii. 27.

Nichols and Broughton's scheme of a navigation from Kingston to Ewell, ii. 230.
 Nith river, report respecting, i. 2.
 ———, Mr. Maxwell's questions respecting the same, 4. answers to, 6.
 North level fens drainage, ii. 283.
 Nose pipe for Carron furnace, i. 400.
 Nottige, Mr., fulling mill at Bocking, ii. 413.

O.

Oil mill at Hull, ii. 398.

P.

Perry, Captain, his improvement of Rye harbour, i. 105.
 Perth bridge, memorial respecting, i. 174. Report of J. Smeaton respecting, 175. Method of fixing the foundation, 188. Shears and tackle used at, iii. 286.
 Peter the Czar's, scheme for joining the Volga and Don, ii. 253.
 Pickernell, Mr., letters to and from, respecting Hexham bridge, iii. 268.
 Pigram, Captain, letter to, respecting Rye harbour, i. 117.
 Pilkington, Sir L., flour mill, ii. 430.
 Plymouth yard, iii. 177.
 Port Glasgow pump, i. 223.
 Port Patrick harbour, iii. 60.
 Portable fire engine, i. 223.
 Portleich, landing places at, iii. 360, 362.
 Potterick Carr drainage, i. 39.
 Pozzelana mortar for water works, iii. 414.
 Pringle, Mr., letters to and from, respecting Coldstream bridge, iii. 235.
 Pudding mill, Blackfriars, ii. 416.

Q.

Queensferry shipping places, iii. 215.

R.

Ramsgate harbour, iii. 74.
 Ravensburn engine, ii. 367.
 Reid, Mr., letters to, respecting Coldstream bridge, iii. 239. Report of on the same, 245. Observations on, 246.

Rieb, Mr., dispute respecting Thurlston mills, i. 239.
 Rosewell, Mr., scheme for the improvement of Lynn harbour, iii. 12.
 Rye harbour, i. 103.

S.

Sandwich haven, iii. 129.
Scarborough pier, iii. 198.
Seacroft Coke furnace, ii. 373.
Sewardston mill, i. 287.
Shears and tackle used at Perth bridge, 5.
Shields dock, iii. 200.
Ship's pump, designed by Mr. Smeaton, i. 356.
Shot mould, explanation of a design for turning, i. 298.
Slide carriages for cannonades, i. 402.
Sluices for cleansing Ramsgate harbour, effects of, iii. 102.
Smeaton, John, memoir of, p. xiii.
Snow, sewer drain, i. 130. 134.
Sowerby bridge canal, ii. 244.
Speern point lights, i. 252.
Stonehouse creek bridge, i. 306.
Stratford, Mr., questions respecting Bristol bridge, i. 99.
Sunderland pier, iii. 194.
Susannah vein at lead hills, ii. 402.
Sutton bridge, iii. 370.
Swale navigation, i. 310.

T.

Tamar navigation, ii. 213.
Tamworth canal, i. 13.
Tetney haven navigation, i. 22.
Thanks river, embankment of a track of mud on, ii. 323.
Thornton paper mill, ii. 426.
Tinmouth harbour, iii. 196.
Tinmouth barracks, iii. 387.
Thurstone mills, i. 239.
Topcliff mill, i. 301.
Torskey drainage, i. 69.
Tottenham mills, i. 290.
Trent river, water road, i. 327.
Trewardreth harbour, iii. 204.
Tyne navigation, ii. 238.
Tyrone canal, ii. 278.

U.

Ure river, navigation, ii. 172. 179.

W.

Wadsworth Carr drainage, i. 39.
Wakefield, navigation to, ii. 131.
 ——— flour mill, ii. 430.
Waltham abbey mills and Bleachfield, i. 279.
 ——— powder mills, i. 28.
Walton, Mr. N., report respecting Tinmouth barracks, iii. 387.
Walton, Messrs., dispute respecting Thurlston mills, 210.
Walton bridge, iii. 371.
Walsingham navigation to, ii. 155.
Watson Brooke, Esquire, questions of, respecting Trewardreth harbour, iii. 204.
Watt and Morrisen's report respecting the navigation of the Forth, i. 147.
Wear river, respecting the situation of the first lock, 182.
Wensley water works, ii. 381.
 ———, Brewhouse, ii. 392.
Wells harbour, iii. 18.
Went river drainage, i. 123.
Westgarth, Mr., hydraulic engine, ii. 376.
Westwick Wath dam, ii. 176.
Whitby harbour, i. 230.
Whitehaven harbour, i. 338.
Whitworth, Mr., scheme of a canal from Kingston to Ewell, ii. 230.
Wilden ferry canal, i. 13.
Winlaton blade mill, ii. 428.
Wisbeach river drainage, ii. 280.
Witham river navigation, i. 26.
Womersley drainage, i. 127.
Wooler, Mr., report respecting Hull river, iii. 168.
 Tyne bridge, 260.
Workington harbour, iii. 170.
Workop corn mill, i. 248.
Worm, in timber, method of preventing its ravages, ii. 178.
Wright, Mr., oil mill at Hull, ii. 398.
Wyburd, Mr., demand on the trustees of the river Lea, i. 290.

Y.

York water works, ii. 342.

THE END.